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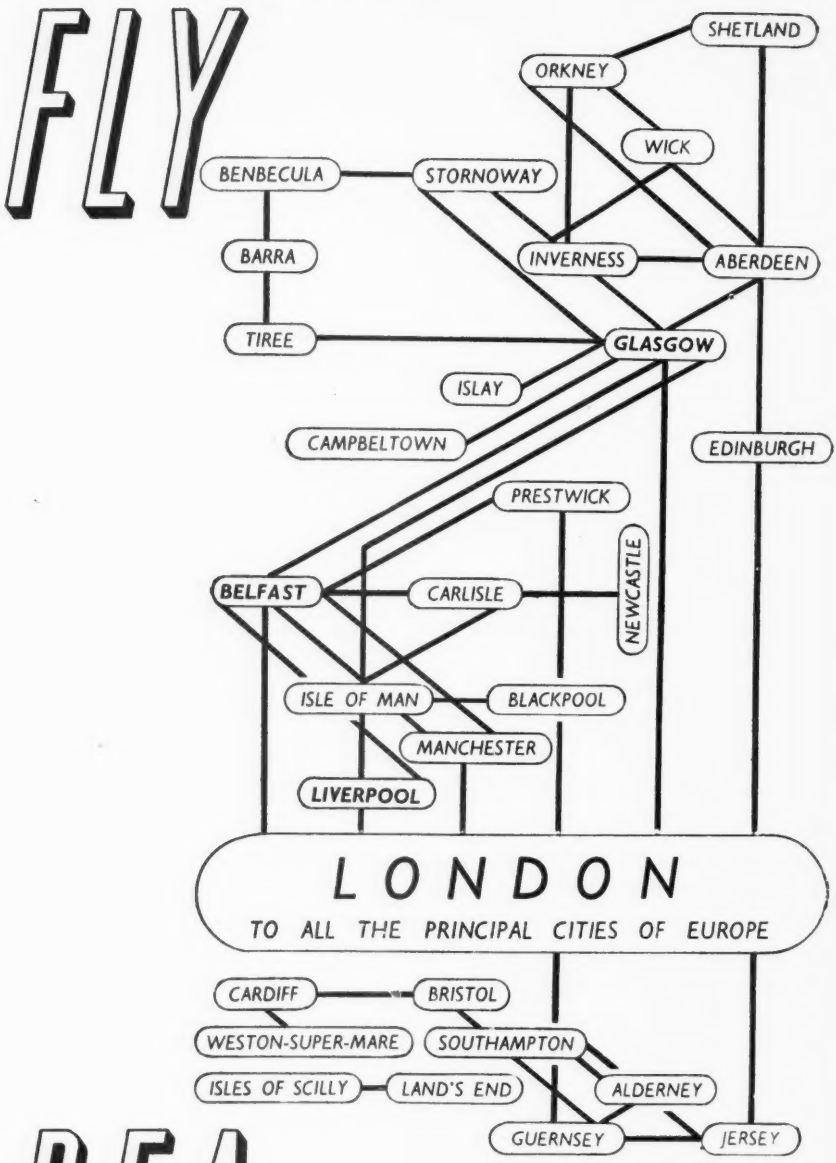
# THE ROYAL AERONAUTICAL SOCIETY

OCTOBER 1947 NO 442 VOL. 51

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# OCTOBER NOTICES 1947

## JOURNAL PREMIUM AWARDS

**The Council have set aside an annual sum of £250 for the award of premiums for papers published in the *Journal* and the Council hope that members (or non-members) will contribute papers on their own special subjects.**

## THE NEW PRESIDENT

Dr. H. Roxbee Cox, D.I.C., B.Sc., F.I.Ae.S., F.R.Ae.S., took office as President of the Society on 1st October 1947.

## CONTENTS OF THE OCTOBER JOURNAL

All Day Discussion on Naval Aircraft.

Papers by W. S. Farren, C.B., M.B.E., M.A., F.R.S., M.I.Mech.E., F.R.Ae.S., "A Survey of the Technical Problems of the Design of Naval Aircraft"; L. Boddington, "Naval Aircraft and Carrier Equipment"; Commander F. M. A. Torrens-Spence, D.S.O., D.S.C., A.F.C., R.N., "Operational Flying." Also, "stills" taken from the films shown during the session by W. G. A. Perring, F.R.Ae.S.

## MR. LINDSEY'S LECTURE

The meeting on 20th November will be a joint meeting with the Institution of Mechanical Engineers. Mr. W. H. Lindsey, M.A., A.F.R.Ae.S., will lecture on "The Development of the A.S. type Gas Turbine."

*The attention of members is drawn particularly to the fact that this meeting will be held at the Institution of Mechanical Engineers, Storey's Gate, S.W.1, at 6 p.m. (Tea at 5.30 p.m.).*

## LECTURES—ADVANCE PROOFS

The Society regrets that because of the severe restrictions on paper and the general difficulties of printing, there will be no advance proofs of lectures read before the Society during the Autumn Session 1947.

Whenever possible, brief summaries of forthcoming lectures will be published in Monthly Notices.

## GARDEN PARTY

A few copies of the Garden Party Programme are still available, price one shilling (1/3 post free).

**"PRESSURISATION" by W. M. Widgery, F.R.Ae.S.**—*Outline of the lecture to be read on 9th October* 1947.

The lecturer gives a broad survey of problems of pressurised aircraft cabins and the associated problems of controlling the internal air conditions, with a brief outline of the physiological aspects of the problem. Heating, ventilation, humidification, refrigeration and so on are discussed, together with a description of existing systems.

The paper concludes with a review of the probable trend of developments.

**"SOME RECENT DEVELOPMENTS IN THE LANDING GEAR FIELD" by R. Lucien, A.F.R.Ae.S.**—*Synopsis of Lecture to be read on Thursday, 6th November* 1947

The paper considers those new factors which have had considerable effect on the landing problem—the increase in speed, wing loadings, gross weights, and operational altitudes and the effect of thin wings. These are considered in relation to functioning strength and retraction requirements.

The ground stability of the tricycle layout is discussed, including problems of freely castoring wheels, shimmy, hydraulically steerable nosewheels, progressive locking at take-off, and systems where all wheels can castor, such as the MacLaren and Goodyear.

The particular requirements of the modern brake are discussed, the need for high energy absorption and good cooling being stressed. A new type of disc brake is illustrated. French requirements as to brake power are discussed as well as the new method adopted in that country for the emergency control of the brakes. Mention is made of the possibilities of aerodynamic braking.

Some particular features of shock absorber performance are investigated, relating to the differentiation between the absorption of landing energy and the good suspension necessary when taxying. Three systems employed in France for obtaining variable orifice control to facilitate this are discussed and illustrated.

Problems of low temperature performance relating to fluids, seals and the effect on metals themselves are mentioned.

The need for increased speed of operation of ancillary services is stressed and details are given of methods using electro-hydraulic controls of various types, and also hydraulic relays. Comparisons are made between such new equipment and electric or pneumatic equivalents.

Particular aspects of strength requirements are investigated and the point is made that since official stressing requirements are based on performance of bad undercarriages, many aircraft are inevitably fitted with undercarriages of excessive strength. Features of the use of welded structures, light alloy castings and forgings, high tensile steel castings and forgings and American welding technique are reviewed and discussed.

The difficulty of undercarriage retraction in a modern machine is considered and unusual geometric solutions which hinge or rotate the wheel, contract the shock absorber travel or make use of tandem wheel arrangements are illustrated.

Special runway equipment, such as the Westinghouse electric trolley, is mentioned.

**SYMPOSIUM ON INTERNAL STRESSES IN METALS**

A Symposium on internal stresses in metals and alloys has been arranged by the Institute of Metals in association with the Faraday Society, the Institute of Physics, the Institution of Mechanical Engineers, the Iron and Steel Institute, the Physical Society and the Royal Aeronautical Society.

The Symposium will be held on **Wednesday and Thursday, 15th and 16th October 1947,** at the Institution of Mechanical Engineers. Thirty-six papers have been received and a limited number of advance copies of the papers will be available at a charge of 5s. (post free). Because of the shortage of paper it is particularly requested that those who are not able to take part in the meeting will await publication of the final report.

The Symposium will be divided into three main sections. The first, under the chairmanship of Dr. C. Sykes, F.R.S., on The Measurement of Internal Stresses; the second

on The Origin, Control and Removal of Internal Stresses, under the chairmanship of Professor L. Aitchison, D.Met., B.Sc., F.R.Ae.S.; and the third on Effects Associated with Internal Stresses, under the chairmanship of Dr. Maurice Cook and Dr. H. J. Gough, C.B., M.B.E., F.R.S. To allow the maximum time for discussion, papers will not be read but will be summarised at the beginning of each session by rapporteurs, who will indicate points on which they consider discussion will be most profitable.

The first session begins at 10 a.m. on 15th October 1947, and ends at 12.45; the second at 2.30 and ends at 5.0 p.m., and the third at 10 a.m. on 16th October and ends at 5.0 p.m.

Further particulars can be obtained from The Secretary, Institute of Metals, 4 Grosvenor Gardens, S.W.1.

## ASSOCIATE FELLOWSHIP EXAMINATION—DECEMBER 1947

The next Associate Fellowship Examination under the present syllabus will be held on 16th and 17th December at home and abroad. All candidates will be sent full instructions and time-table.

## LECTURE PROGRAMME—AUTUMN SESSION 1947

The Lectures will be held at 6 p.m. in the Lecture Hall of the Institution of Civil Engineers, Great George Street, S.W.1 (by permission of the Council of the Institution) unless otherwise stated. Tea will be served at 5.30 p.m.

Visitors are welcome, but should obtain tickets through a member of the Society.

**Thursday, 9th October 1947**—Pressurisation of Aircraft, by W. M. Widgery, F.R.Ae.S.

**Thursday, 23rd October 1947**—The Problem of High Temperature Alloys for Gas Turbines, by Sir William T. Griffiths, D.Sc., F.R.I.C., F.Inst.P., F.I.M.

**Thursday, 30th October 1947**—The Third British Commonwealth and Empire Lecture, by James Bain of Trans-Canada Airlines.

**Thursday, 6th November 1947**—Some recent Developments in the Landing Gear Field, by Captain R. Lucien, A.F.R.Ae.S.

**Thursday, 20th November 1947**—The Development of the A.S. Type Gas Turbine, by W. H. Lindsey, M.A., A.F.R.Ae.S. Joint meeting with the Institute of Mechanical Engineers. *This meeting will be held at the Institution of Mechanical Engineers, Storey's Gate, S.W.1, at 6 p.m. (Tea at 5.30 p.m.).*

**Thursday, 4th December 1947**—Problems Facing Civil Airline Operations, by N. E. Rowe, C.B.E., B.Sc., D.I.C., F.R.Ae.S.

**Thursday, 18th December 1947**—The Work of the High-Speed Tunnel, by Professor A. Thom, M.A., D.Sc., and W. G. A. Perring, F.R.Ae.S.

## BIRMINGHAM BRANCH

The annual dinner of the Birmingham branch is to be held at the White Horse Hotel, Birmingham, on Saturday, 11th October. This is to be followed by a concert for which special artists are being engaged.

The tickets for the dinner and concert are 22/6 for a double ticket and 12/6 for a single ticket.

Application for tickets to Mr. C. P. Homes, 81 Peplins Way, Birmingham, 30.

**24th October 1947**—Film evening. At Queen's College Chambers, Paradise Street, Birmingham, at 7 p.m.

## GLOUCESTER AND CHELTENHAM BRANCH

**15th October 1947**—Pressurisation of Aircraft, by Mr. W. H. Widgery, F.R.Ae.S.

In the Chemistry Lecture Theatre, Cheltenham Grammar School, at 7.30 p.m.

## PRESTON BRANCH

**Thursday, 9th October 1947**—Modern Landing Gear Practice, by H. G. Conway, M.A., A.M.I.Mech.E., A.F.R.Ae.S. (Technical Director of British Messier Ltd.).

**Wednesday, 29th October 1947**—Aircraft Production in War and Peace, by L. G. Burnard, A.M.I.P.E. (Vickers-Armstrongs Ltd., Aircraft Section).

**Wednesday, 19th November 1947**—The Probable Role and Influence of Aircraft in Future Warfare, by Air Marshal Sir Robert H. M. S. Saundby, K.B.E., C.B., M.C., D.F.C., A.F.C

**Wednesday, 10th December 1947**—Fighter Design, by Professor R. L. Lickley, B.Sc., F.R.Ae.S. (Professor of Aircraft Design at the College of Aeronautics, Cranfield).

Unless otherwise stated, all lectures will be held at 7 p.m. in the Preston Chamber of Commerce, Fishergate (next to the Theatre Royal).

## READING BRANCH

**Wednesday, 5th November 1947**—The Place of the Model in Aeronautical Research, by W. G. A. Perring, F.R.Ae.S. In the Monthly Staff Dining Room, Miles Aircraft Ltd., The Aerodrome, Woodley, Berks., at 6 p.m. (tea at 5.30 p.m.).

## SOUTHAMPTON BRANCH

**5th November 1947**—The Case for Tailless Aircraft, by E. D. Keen, F.R.Ae.S.

**3rd December 1947**—Recent Development in Flying-Boats, by H. Knowler, A.F.R.Ae.S.

**7th January 1948**—Rotating Wing Aircraft, by C. G. Pullin.

**4th February 1948**—Structures Testing by P. B. Walker, M.A., Ph.D., F.R.Ae.S.

Lectures will be held at University College, Southampton, at 7 p.m.

## GRADUATES' AND STUDENTS' SECTION

**Tuesday, 21st October 1947**—Interplanetary Flight and Rocket Propulsion, by Mr. A. V. Cleaver, A.R.Ae.S., Special Projects Engineer, De Havilland Engine Co. Ltd.

**Tuesday, 4th November, 1947**—Maintenance Difficulties in the Field, by Mr. M. J. Kemper, M.B.E., A.R.Ae.S.

**Wednesday, 19th November, 1947**—Aircraft Photography, by Mr. John Yoxall, Art Editor of *Flight*.

**Friday, 12th December 1947**—Aircraft Design from the Airline Point of View, by Mr. Christopher Dykes, Deputy Chief Project Engineer, B.O.A.C.

Lectures will be held in the Library of the Society, 4 Hamilton Place, W.1, at 7.30 p.m.

### Dance

The Annual Dance, open to members and their friends, will be held on Friday, 17th October 1947 at the Royal Hotel, Woburn Place, W.C.1 (nearest Tube Station, Russell Square—Piccadilly Line). Tickets, price 5/- each, may be obtained from the Honorary Secretary, J. G. Roxburgh, 62 Fitzjohns Avenue, London, N.W.3, or from the Section's representatives at firms and colleges.

## CHANGES OF ADDRESS

To assist in keeping the records of members correct and up to date the Secretary will be glad if all members will notify him as soon as possible of changes of address.

When notifying changes please give the following particulars:—

Name (in block letters).
Grade of membership.
New address (in block letters).
Old address.

Changes of address must be received *before the 15th of the month* in order to be effective for the Journal for the following month.

## ELECTION OF MEMBERS

The following new members have been elected:—

*Associate Fellow*

M. V. Govinda-Raghavan.

*Associates*

James L. Heron, Denis Keogh Kempston (from Graduate), George Harold Thomas, Frederick Wheate, Henry John Banfield Thompson.

*Graduate*

James Insley Osborne.

*Students*

Margaret Elizabeth Angas, Rupert Page Brown, James Joseph Thompson, Keith Donald Thomson, John William Herbert Woof.

## ACKNOWLEDGMENTS

The Council acknowledge with grateful thanks back numbers of the Journal from Captain A. N. Barrett, A.F.R.Ae.S., J. D. Campbell, A.F.R.Ae.S., and T. H. Tarr, A.R.Ae.S., and a copy of " Le Vol Vertical " by Lt.-Col. Lamé, presented to the Library by G. Korab, Esq.

## ADDITIONS TO THE LIBRARY

A.a.337—Cinématique de l'avion. Francois Hussenot. Dunod, Paris. 1947.

B.g.154—Jane's All the World's Aircraft. Leonard Bridgman (comp). Sampson Low. 1947.

BB.b.131—Calcul et construction des avions légers. R-G. Desgrandchamps. Libraire des Sciences Aeronautiques. 1947.

BB.b.132—Plan de fabrication aéronautique. M-P. Guibert. Dunod, Paris. 1945.

EE.b.92—*Achievement. Rolls-Royce Ltd.* 1947. (Y.7).

EE.b.120—Aircraft Engines of the World. Paul H. Wilkinson. Pitmans. 1947.

L.d.116—*Notices to Airmen. Nos.* 229, 230, 231, 232, 233, 234, 235, 236, 237, 238, 241, 242, 243, 244, 245, 247, 248, 249, 250, 252, 253, 254, 255, 256, 257, 258.

Q.a.176—*Select list of standard British scientific and technical books. ASLIB.* 1946.

S.e.141—German Research in World War II. Leslie E. Simon. John Wiley, New York. 1947.

TT.a.54—The Flying Bôat. Herbert Strang. Milford. 1919.

**Australian Council for Aeronautics**

*C.S.I.R. Report No.* 27. *A review of turbulence theories. B. L. Cuming.*

*A.C.A. Report No.* 28. *Review of current methods for strength testing of aircraft win W. W. Johnstone.*

*A.C.A. Report No.* 29. *The buckling of plywood plates in shear. R. C. T. Smith.*

**A.R.C. Reports and Memoranda**

2130—*Equations to given aerofoil sections: "Clark Y" and R.A.F.6. R. C. Pankhu*

2115—*Some notes on aerodynamic derivatives. W. J. Duncan.*

2093—*Drag measurements on N.A.C.A. 2218 section at compressibility speeds for co parison with flight tests and theory. H. H. Pearcey.*

2133—*The development of turbulent boundary layers. H. C. Baines.*

2112—*A new method of two-dimensional aerodynamic design. M. J. Lighthill.*

2129—*The smallest size of a spanwise surface corrugation which affects boundary la transition on an aerofoil. A. Fage.*

2117—*Aerodynamic forces on wings in non-uniform motion. W. Prichard Jones.*

2028—*A continuation of longitudinal stability and control analysis. Part II. Interpretat of flight tests. S. B. Gates and H. M. Lyon.*

2103—*Effect of damping in different parts of an aircraft structure on forced vibrati as studied on simplified systems. S/L. Fiszdon, R. P. N. Jones and D. L. Woodco*

2099—*Stress distribution in reinforced flat sheet, cylindrical shells and cambered b beams under bending. D. Williams and M. Fine.*

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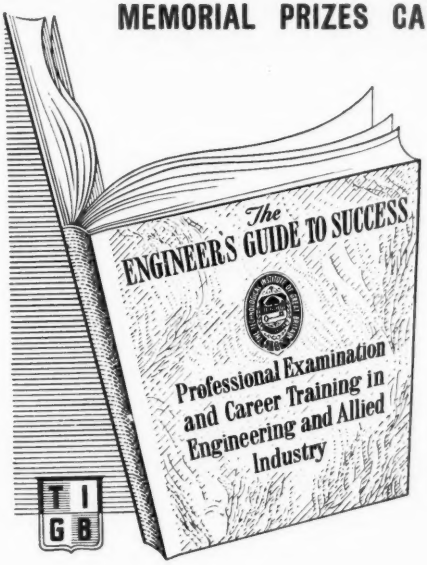


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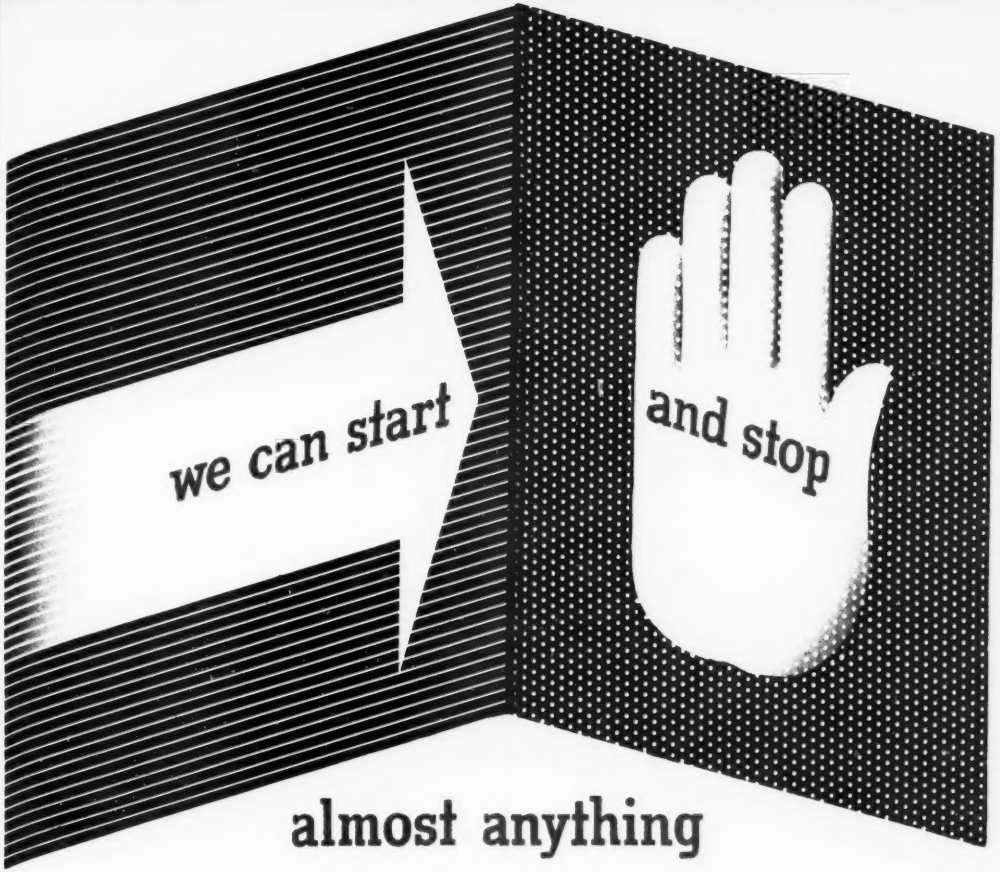


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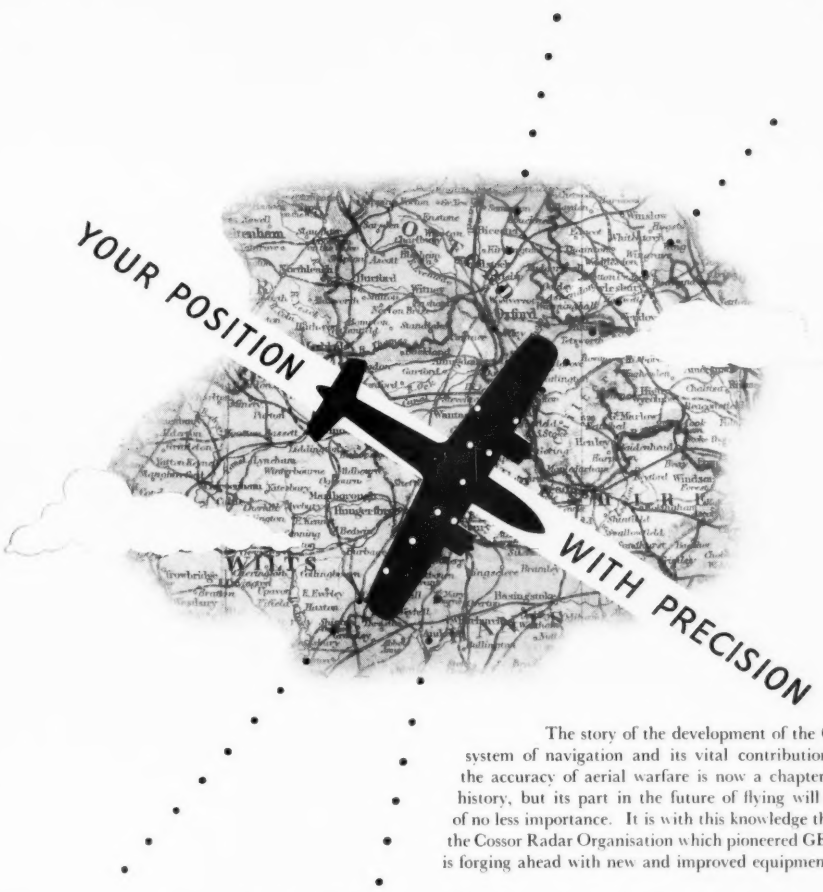


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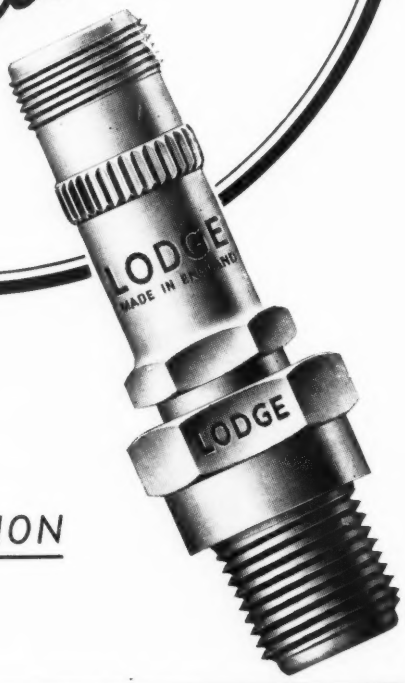


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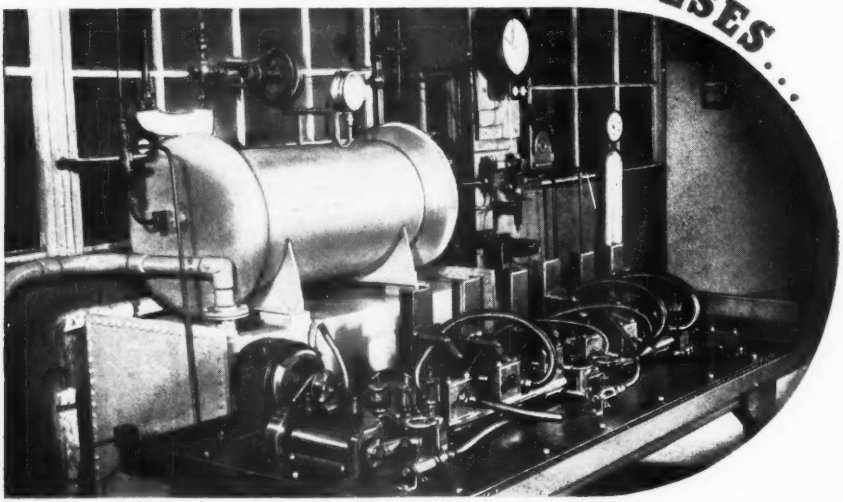

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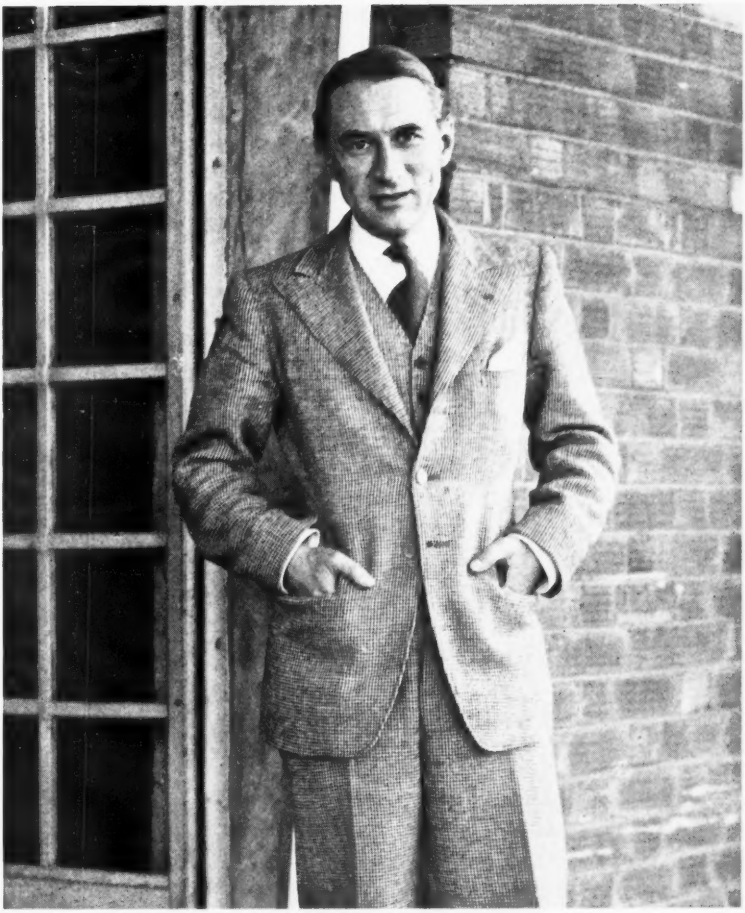

H. ROXBEE COX, Ph.D., D.I.C., B.Sc., F.I.Ae.S., F.R.Ae.S.

President of the Royal Aeronautical Society, 1st October 1947.

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THE ROYAL AERONAUTICAL SOCIETY

# NAVAL AIRCRAFT

A FULL DAY discussion on Naval Aircraft was held in the Lecture Hall of the Institution of Civil Engineers on Wednesday, 7th May, 1947 at which the 713th, 714th and 715th papers were read before the Society. In addition, films illustrating deck-landing and launching operations were shown during the afternoon session by Mr. W. G. A. Perring, F.R.Ae.S., Director of the Royal Aircraft Establishment. In the chair, the Vice-President, Dr. H. Roxbee Cox, F.R.Ae.S. and Sir John Buchanan, F.R.Ae.S.

**Morning Session—In the chair, Dr. H. Roxbee Cox.**

## A SURVEY OF THE TECHNICAL PROBLEMS OF THE DESIGN OF NAVAL AIRCRAFT

*by*

**W. S. FARREN, C.B., M.B.E., M.A., F.R.S., M.I.Mech.E., F.R.Ae.S.**

*Mr. Farren obtained his degree at Trinity College, Cambridge. From* 1915 *to* 1918 *he was in charge of Aerodynamic Experiment and Design at Farnborough and then joined the Technical Staff of Armstrong-Whitworth Ltd. From* 1920 *to* 1937 *he was University lecturer in Engineering and Aerodynamics at Cambridge. In* 1937 *he became Deputy Director of Scientific Research at the Air Ministry and in* 1939 *Director of Research and Development (Aircraft) Air Ministry. He was appointed Director of Technical Development in* 1940 *and in* 1941, *Director of the Royal Aircraft Establishment, Farnborough. Since* 1946 *he has been Technical Director of Blackburn Aircraft Ltd.*

### 1. INTRODUCTION.

IN a necessarily brief introduction it is best to choose a few topics which seem to me to be of first-class importance, and to leave it to the discussion to bring up others.

I wish it had been possible to include one other aspect of Naval aircraft in these introductory papers— the aircraft carrier. Many of the technical aspects of carriers may be more appropriate as a subject for the Institute of Naval Architects, but I feel that our discussion will be incomplete unless ship designers contribute.

### 2. SOME QUESTIONS AND ANSWERS.

(*i*) What are "Naval aircraft"? From the point of view of to-day's discussion, they are aircraft which operate from ships and often, although by no means always, as part of a Naval force.

(*ii*) Do Naval aircraft differ essentially from land-based aircraft? I think there is no essential difference between their functions and those of land-based aircraft, but there is a difference of emphasis. Technically, Naval aircraft are influenced strongly by the fact that they are carried in, take off from and

land on, ships. Moreover, the functions of the ships from which and with which they work, lead to an emphasis on large radius of action or long duration of flight which has far-reaching technical consequences.

(*iii*) Will there continue to be Naval aircraft? My answer to this is a series of assumptions.

(1) In view of the experience of the past 35 years, mere prudence compels us to prepare against the possibility that war may once again be forced on us.

(2) We must try to forsee what kind of war this might be, in the light of the developments which have taken place in the past few years in the power of man over material.

(3) In spite of the doubt which these developments cast on the continuing usefulness of many techniques and weapons, there will be a need for aircraft operating from ships.

(4) The chief functions of Naval aircraft will be the attack of hostile submarines, aircraft, and ships—and probably (although this assumption is not essential to my argument) in that order of importance.

(5) There will continue to be two main kinds of ship bases: (*a*) specialised aircraft carriers, amenable to the same processes of research and development as aircraft; (*b*) simpler, smaller and slower ships, which will be required in numbers at a time which cannot be accurately foreseen and must therefore be provided then by conversion of ships designed primarily for other purposes.

Although my survey will be almost entirely technical, I have found it necessary to venture outside the technical field in order to find a satisfactory starting point. I am not content to take it for granted that there will be a need for a weapon in the future merely because it has been useful in the past. I think it is our business as engineers to be satisfied about answers to the above questions before we pass to technicalities. My own answers may not satisfy you, but we must agree substantially on grounds for answering "Yes" to my third question, if the rest of our discussion is to serve any useful purpose.

## 3. NAVAL AIRCRAFT DESIGN IN RELATION TO ADVANCES IN WEAPONS AND RADAR.

For the functions of Naval aircraft which I have mentioned they must be armed—and armed with both weapons and radar. Like aircraft, armament is ever changing and developing and many of its most significant developments occur after the conflict has begun. It has always been difficult to plan the development of aircraft and of armament so that those responsible for each have always precisely the necessary and sufficient information about the other, culminating in the appearance at the right time of the perfect aircraft properly equipped. Such a policy presupposes the existence of superhuman wisdom—not to mention other rare qualities—in too many people.

There is everything to be said for close co-operation between those busy with the design and development of aircraft and of armament. But I think experience has shown that the best way to get good aircraft with the right armament at the right time is to prefer a type of layout which is flexible; that is to say, where fairly large changes in certain substantial components can be made without affecting either other major components or the efficiency of the aircraft.

There is another advantage in this method. A flexible layout makes a versatile aircraft, one which can readily be turned to a variety of uses. For Naval aircraft versatility has great advantages. I am aware that such a policy, if pursued blindly and without judgment, will lead to "general purpose" aircraft of no merit. But there are several outstandingly successful examples of its application and I see no reason to believe that a high degree of versatility in function is incompatible with technical quality.

## 4. NAVAL AIRCRAFT AND THE CARRIER.

The operation of aircraft from ships leads in effect to an additional set of technical requirements. In the past, these have generally been regarded as an additional burden on the aircraft and have been held to justify the view that Naval aircraft must necessarily be inferior to land-based aircraft. Some Naval aircraft may not attain the highest standard of technical efficiency, in the narrow sense, but this is due rather to exceptionally difficult operational requirements than to the fact that they operate from ships. There are types of Naval aircraft, however, and these are on the whole the more stimulating to the designer, for which I believe a more thorough exploitation of the potentialities of the carrier can assure a standard of technical and operational efficiency no lower, and perhaps higher, than that of comparable land-based aircraft. To this achievement the carrier designer must make a contribution.

The chief technical aspects of aircraft design on which the carrier has a direct influence are the take-off and the landing. In Fig. 1 the results of conventional calculations of take-off from the higher class of carrier are summarised. They do not disclose any outstanding technical problem until we come to aircraft of very high speed, leading to swept-back wings and a low maximum lift. But for such aircraft and indeed for the majority of first-line Naval aircraft, I believe that the take-off will become more and more a responsibility of the carrier and less and less that of the aircraft. Free take-off will be practicable, but a really enterprising development of "assisted take-off" could provide operational advantages far greater than any development of the aircraft which I can foresee.

I feel that the power available in the carrier has never been fully exploited on behalf of its aircraft. A carrier should not be regarded as merely a movable airfield. It carries within it sources of power far beyond what could be economically provided at land bases, except possibly by tapping a central electric supply. Save for a small fraction, this power is at present exploited only in the carrier's speed. I suggest that it could be used directly, to "project" the aircraft into the air under any conditions, irrespective of weather, of the speed of the carrier, or of its direction of travel and at a rate greatly exceeding what can be achieved by any combination of the aircraft's own power plant and catapults, or rockets, as we know them. I believe that the design of future carriers will centre round this potentiality. I admit that there are many handling problems to be solved, demanding a high degree of mechanisation, with all that it implies in the way of liability to break down. But I see no reason to believe that these difficulties cannot be overcome.

For the second-line ship such developments are not practicable and a "free " take-off is essential. There seems no sufficient reason to exclude the use of rockets, which are a cheap and effective way of getting a large weight into the air. The present view—that they should be reserved for emergencies—is, I think, unlikely to survive and I see no reason to believe that existing rockets, although very efficient, cannot be greatly improved from the operational point of view.

The take-off of aircraft suitable for this class of carrier is covered by Fig. 2 and a study of this shows that, with appropriate and economical thrust/weight ratios, there is still something to be gained by a rise in lift, but it is doubtful whether elaborate developments in the direction of very high lift coefficients will pay. They would be most useful in emergencies when rocket assistance, a far lower economical burden on the aircraft, is surely acceptable.

It is chiefly in the landing of aircraft on carriers that aircraft design has still to make a substantial advance. This applies particularly to the higher class of aircraft. Figs. 3 and 4 summarise the situation of our

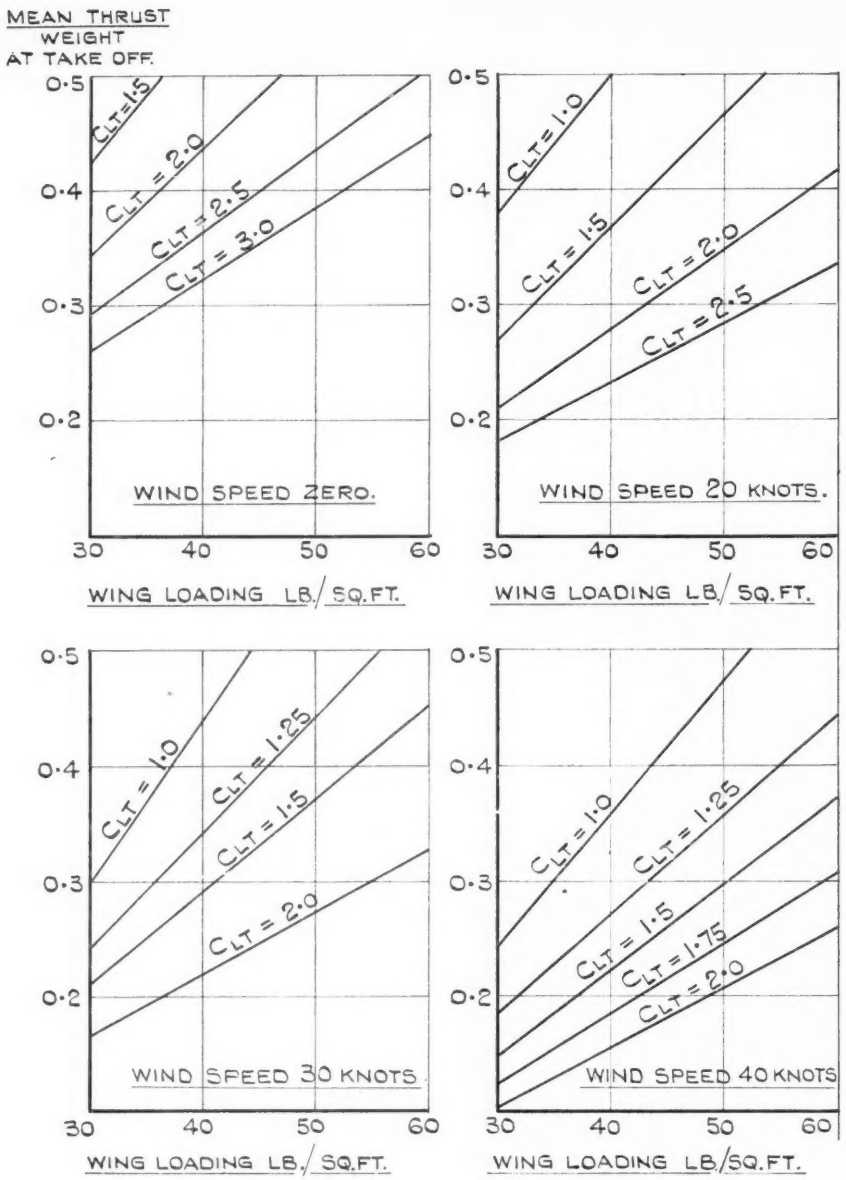



Fig. 1.

Free take-off from Fleet carriers.

Assumptions: Take-off distance 700 ft.; carrier wind speed 0 to 40 knots; allowances made for deck friction and air drag.

The diagrams show: The relation between wing loading, lift coefficient and thrust/weight ratio at take-off.

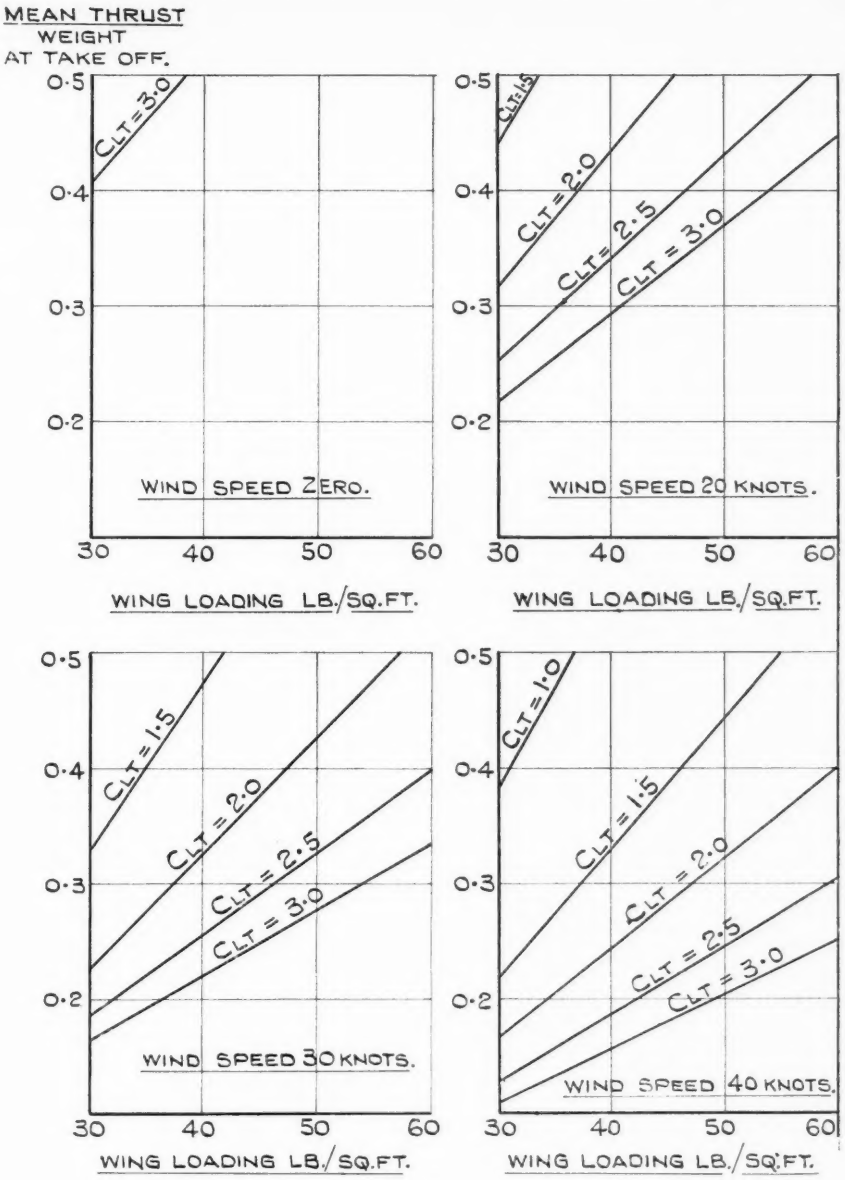



Fig. 2.

Free take-off from pocket carriers.

Assumptions: Take-off distance 400 ft.; carrier wind speed 0 to 40 knots; allowances made for deck friction and air drag.

The diagrams show: The relation between wing loading, lift coefficient and thrust/weight ratio at take-off.

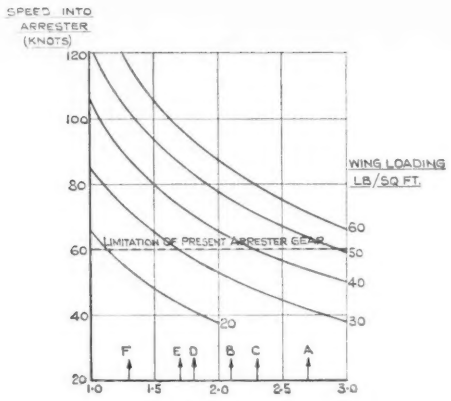



Fig. 3.

Maximum lift coefficient (engine off)

| | | $C_L$ max |
|---|---|---|
| A | Cambered section, high lift flaps (probably full span) ... ... ... | 2.8 |
| B | Cambered section, normal flaps ... | 2.1 |
| C | High-speed section, high lift flaps (probably full span) ... ... ... | 2.3 |
| D | High-speed section, normal flaps ... | 1.8 |
| E | Swept-back wing, high-speed section (special lift devices) ... ... | 1.7 |
| F | Swept-back wing, high-speed section large flaps ... ... ... ... | 1.3 |

Landing of a jet-propelled aircraft on a Fleet carrier.

Assumptions: Approach at 1.25 times stalling speed (engine off); carrier wind speed 30 knots; speed into arrester = approach speed relative to carrier.

The diagram shows: The relation between wing loading (at landing weight), maximum lift coefficient and speed into arrester.

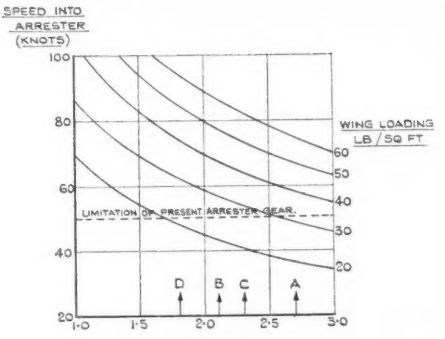



Fig. 4.

Maximum lift coefficient (engine off)

| | | $C_L$ max |
|---|---|---|
| A | Cambered section, high lift flaps (probably full span) ... ... ... | 2.8 |
| B | Cambered section, normal flaps ... | 2.1 |
| C | High-speed section, high lift flaps (probably full span) ... ... ... | 2.3 |
| D | High-speed section, normal flaps ... | 1.8 |

Landing of a propeller-driven aircraft on a pocket carrier.

Assumptions: Approach at 1.1 times stalling speed (engine off); carrier wind speed 15 knots; speed into arrester = approach speed relative to carrier.

The diagram shows: The relation between wing loading (at landing weight), maximum lift coefficient and speed into arrester.

knowledge up to date and show that both classes of aircraft would gain—the higher class materially—by an improvement in the lift coefficient under conditions of the approach.

It seems to me surprising that so little has been done to exploit specific aerodynamic devices with the object of attaining good approach lift coefficients. We need a relatively high lift coefficient under conditions of entirely satisfactory control and therefore, almost necessarily, remote from the condition of the stalled wing. We have still to exploit the full potentialities of flaps, slots, spoilers and suction.

I have said that the approach should be in a condition reasonably remote from the stall. In the past, approach speeds and general conditions were such as to make a small margin, in relation to the inevitable collapse at the stall, an acceptable risk. But in future the consequences of a mistake will be too serious. What is needed is freedom from vice at the stall, combined with first-class control at an appreciably higher speed —and a first-class view. This combination gives the pilot a fair chance. The burden is then on the arrester.

Figure 5 combines the two investigations, on certain reasonable assumptions. For the higher class of aircraft where, even with special aerodynamic devices, the maximum lift coefficient is likely to be low, there would be a big reward for increasing the speed which

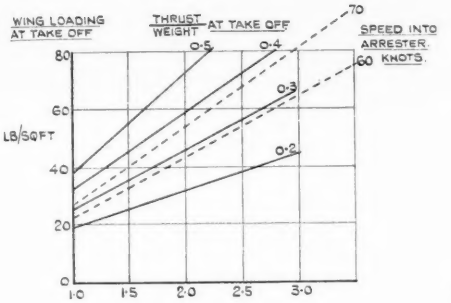
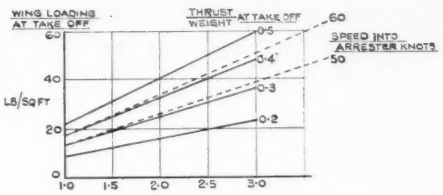



Fig. 5.

Maximum lift coefficient (engine off)

Jet aircraft and Fleet carriers

Assumptions: Take-off distance 700 ft.; carrier wind speed 30 knots; take-off speed 1.1 × stalling speed (engine off); approach at 1.25 × stalling speed (engine off); landing weight 80 per cent. of take-off weight.




Maximum lift coefficient (engine off)

Propeller aircraft and pocket carriers.

Assumptions: Take-off distance 400 ft.; carrier wind speed 15 knots; take-off speed 1.0 × stalling speed (engine off); approach at 1.1 × stalling speed (engine off); landing weight 92 per cent. of take-off weight.

The diagrams show: Relations between wing loading at take-off and maximum lift coefficient (engine off) for fixed values of thrust/weight at take-off and speed into arresters.

the arrester would accept. A rise of 10 knots in the neighbourhood of 60 knots leads to a gain to the aircraft about equal to what would be produced by a rise in maximum lift coefficient of 0.5, namely an increase in permissible wing loading of 20-25 per cent. The take-off thrust/weight ratio available is likely to be sufficient for free take-off using the full deck length. For the more modest aircraft, where take-off must be possible under the aircraft's own power, the present arrester speeds are probably high enough for a good economic compromise. A good maximum lift coefficient can be attained on such aircraft without abnormal devices, but a rather higher lift coefficient, available both for take-off and approach, would be worth while, so long as the means of attaining it were light and simple.

There is one other technical problem of Naval aircraft which I think it is appropriate to mention here and that is the undercarriage. The stowage of the undercarriage is a difficult problem in the design of any aircraft and in very high-speed aircraft it almost dominates the design. Now a carrier is the only kind of airfield where it seems likely to be operationally and economically practicable to transfer the shock absorbing mechanism from the aircraft to the deck. At the same time it has available the power for mechanising the handling of the aircraft when on the deck, without the aircraft itself having any wheels.

I am aware that this possibility is being considered, but I hope it will be actively discussed to-day. I will leave it to others to state the difficulties and objections and confine myself to the main advantages which it would confer on the aircraft.

(1) *Drag.* Very high-speed aircraft require thin wings. The undercarriage distorts the aircraft from the most efficient form.

(2) *Weight.* There would certainly be a considerable saving in weight, after making full allowance for the necessary stiffening of the belly, primarily because of the great structural simplification which would result. The most effective way to lighten a structure is to simplify it.

(3) *Stiffness.* This is the chief structural problem of really high-speed aircraft. It is made doubly difficult by the holes needed to house the undercarriage.

(4) *Power plant installation.* Efficient ducting of the air to and from a jet unit is essential. If there were no undercarriage to house, better ducts could be used.

(5) *Fuel capacity*. For Naval requirements the largest possible amount of space is required for fuel. By eliminating the undercarriage, the prospects of providing it would be improved.

I believe the resulting aircraft would be superior to its land-based counterpart. If so, this seems to be a case where the undoubted difficulties and disadvantages are rather a statement of what has to be overcome, than a reason for not making the effort.

## 5. ECONOMICS OF NAVAL AIRCRAFT DESIGN—RADIUS OF ACTION.

There is no single or simple criterion of merit of an aircraft—unless of course it aims at breaking some record. But there is a kind of technical balance sheet which summarises what I call the "economics" of its design. This consists of a weight account, a drag account and a speed-height-load-range account. Such a survey of Naval aircraft shows up two outstanding features. The first is a tendency to a high percentage structure weight caused, in the main, by "ship-borne" requirements. The second is the dominating effect of the large radius of action, or duration of flight, which is essential for all Naval aircraft.

Structurally, the Naval aircraft has all the problems of land-based aircraft, with the addition of wing-folding and an exceptionally high undercarriage strength and shock-absorbing capacity. Recent experience has shown that the weight penalty involved in folding, including the provision of power operation, can be reduced to a much lower figure than was accepted as inevitable a few years ago for manual operation. This improvement is mainly because of the adoption of a much simpler type of folding and a basically simple wing structure.

The undercarriage problem also can be reduced by using a basically simple arrangement. The essential parts can be strengthened and the extra shock absorption provided, for a small penalty in weight.

When everything possible has been done to reduce the burden of these two requirements, it must be recognised that they do lead to a rise in structure weight. This emphasises the difficulty of meeting the range requirement.

There is no mystery about the technical measures necessary to ensure the greatest possible radius of action of an aircraft. The requirements are not peculiar to Naval aircraft, or indeed to aircraft at all. If all the heat energy in a pound of aircraft fuel could be turned into work, it would lift rather more than a ton—about 2,500 lb.—by a nautical mile. If turned to propulsion, it would push something having a drag of this amount by the same distance. Hence we get the simple relation:

> Range (nautical miles) = 2,500 × Fuel burnt (lb.) × Efficiency of conversion into propulsive thrust ÷ Drag (lb.).

So what we have to aim at is the greatest possible amount of fuel, a high efficiency of conversion and a low drag. Moreover, all these factors are of equal importance.

I do not propose to enter into the aerodynamics of aircraft drag. But it is in no way misleading to emphasise that drag rises with speed and in general, from the point of view of the aircraft's contribution to a good range, it pays to travel slowly. Under all circumstances, however, it pays to eliminate the *causes* of high drag. An aerodynamically bad aircraft—one with a high specific drag—is not only a slow aircraft, it is also an uneconomical one.

What I have called the "efficiency of conversion" of the power unit can be expressed in terms of familiar quantities.

For a propeller plant it is proportional to

$$\frac{\text{propeller efficiency}}{\text{fuel consumption per hour per B.H.P.}}$$

For a jet plant it is proportional to

$$\frac{\text{speed of aircraft propelled}}{\text{fuel consumption per hour per lb. of thrust}}$$

The propeller is a remarkable device, giving a high and fairly uniform efficiency over a wide range of speed. The jet, as at present developed, is efficient only at high speeds. Since the aircraft's drag rises with speed we have a conflict of technical requirements. Fortunately, the jet power plant leads to the lowest drag so far achieved in aircraft and for some purposes the balance, on an assessment of weight of power plant and fuel for a given (and by no means short) range, seems to be in its favour.

I have made several attempts to express these statements in figures or diagrams which would be a reliable guide to the general situation, but I have come to the conclusion that, apart from one simple comparison, it is not possible to generalise with safety and each case must be treated in some detail. This means an elaborate investigation, which is not appropriate for an introduction to a discussion. But an estimate of the "efficiency of conversion" for typical power units of the three kinds is sufficient to draw attention to my main point.

With a propeller efficiency of 80 per cent. and a specific consumption of 0.45 lb. per B.H.P. hour the figure for the petrol engine is 24 per cent. For the gas turbine, with the same propeller efficiency and about a 50 per cent. higher consumption, it is about 16 per cent. For a jet unit consuming 1 lb. of fuel per hour per lb. of thrust, it is 10 per cent. at 300 m.p.h., rising with speed. Even allowing for the differences in weight of the power units and for the lower drag of the gas turbine and jet aircraft, there will be a big reward for a substantial reduction in the fuel consumption of gas turbines and jet units. This is particularly important at outputs of the order of $\frac{3}{4}$ of the maximum.

It is of course more than likely that more economical turbines will be heavier. No decision is possible until we have more information. But for Naval aircraft, where the operational requirement for large radius of action and long flight duration is likely to increase, it is important that we should know what can be done. It seems early yet, even allowing for the high rate of development of the jet unit in the past few years, to accept that nothing better is possible.

The jet unit can be given a higher efficiency by what amounts to a mechanically efficient way of entraining more air and so increasing the size of the jet. The ducting problem may be difficult and there is probably an appreciable weight penalty. But again there is a prospect of a good dividend and no clear answer until we have the facts.

All things considered, Naval aircraft have a special interest in essentially economical power units. This is in no way an argument for the large, heavy, high-drag unit, but a challenge to those who have produced such outstandingly light and powerful units to recognise that aircraft have, in more senses than one, a long way to go.

## 6. CONCLUSION.

It has been said, I think truly, that aircraft engineering is not essentially different from ordinary engineering, but is more difficult. Success depends upon achieving throughout a higher standard than is either technically necessary, or economically allowable, in most other fields. The technical problems of the design of Naval aircraft seem to me to be essentially the same as those of land-based aircraft, but more difficult. Unless the standard of ingenuity and enterprise applied to Naval aircraft is even higher than that accorded to land-based aircraft, they will be inferior.

There is still one field of aerodynamics where exploitation of results known in principle to be achievable is called for. The objective is to attain a higher lift coefficient on the approach, with adequate control in all directions and freedom from vice at the stall. For very high-speed aircraft the basic knowledge in this field is inadequate and needs extending by research.

In the interest primarily of the greatest possible radius of action, or duration of flight,

reduction of drag is of the greatest importance for all types of Naval aircraft.

Most aircraft would profit by an improvement in the economy of their power plants. The burden on Naval aircraft is such that they demand an improvement. This may necessitate the development of power units for their specific requirements.

The carrier is the source of the special problems of the design of Naval aircraft and it should share in providing their solution. Its power should be exploited to project the aircraft into the air under all conditions and to handle them both below and on deck.

A rise in the speed the arrester will accept would produce a valuable improvement in the higher class of aircraft. The promise of still greater improvement is contained in the prospect of an elimination of the undercarriage from the aircraft, transferring shock absorbing to the deck.

If enough effort can be devoted to the development of the potentialities of the carrier, Naval aircraft can be sure of being not only as good as, but possibly better than, corresponding land-based aircraft.

## 7. ACKNOWLEDGMENT.

The diagrams, Figs. 1 to 5 and the calculations upon which they were based, were made by members of the staff of the Aerodynamics Department of Blackburn Aircraft Ltd., to whom I wish to express my thanks.

# DISCUSSION

**Sir Charles S. Lillicrap**, K.C.B., M.B.E. (Director of Naval Construction): Nothing but good could come from the full co-operation between the designers of Naval aircraft and the aircraft carrier designers. They had many problems to face in common and the aircraft carrier designer had to play his part in the development of Naval aircraft.

Mr. Farren's assumptions were sound. He also agreed emphatically with his conclusions that there was no reason why Naval aircraft should be inferior to land-based; in fact, with development, it was a high probability that Naval aircraft could be superior to land-based aeroplanes. The policy of flexibility in design could be carried a great way but the time inevitably came, and soon, when possible alterations destroyed the balance of the design and the result was that the carrier gave no satisfaction to anyone.

He was not quite sure what Mr. Farren meant about the potentialities of the aircraft carrier not having been sufficiently developed, but he assumed it meant the development of the catapult and assisted take-off gear. It was many years since catapults were first installed in ships. All aircraft carriers had them but it was true that their potentialities had not been fully exploited. In recent years they had not been much used and a few years ago it was not uncommon for suggestions to be made that they were quite unnecessary and should be removed. That attitude had gone. With the modern aircraft, assisted take-off was essential.

The same applied to the arrester gear which had been, and was, a matter of continuous and rapid development. In the *Illustrious* and *Implacable* classes they had arrester gear to deal with aircraft entering at 60 knots relative speed and catapults capable of projecting aircraft at a relative speed of 66 knots. In later designs of aircraft carriers, the speed for the arresting gear had gone up to 75 knots for the heaviest aircraft and considerably higher speeds could be accepted for lighter aircraft, provided always that the aircraft could be designed to withstand a deceleration of 3g. One of the limitations imposed on arrester gear in the past had been the requirement that the aircraft must not be subjected to a retardation exceeding 1.5g. and they had only recently moved away from this figure, first to a value of 2g. and quite recently to 3g. Now that the figure of 3g. retardation had been accepted for future

aircraft designs they anticipated being able to produce arresting gear with a greatly improved performance which would cater for any type of Naval aircraft that was likely to be produced or designed in the next decade.

It was now accepted that catapults should be considered the primary method of take-off. Future catapults would have a much higher performance than those fitted in existing carriers, or those being fitted in carriers now building. Catapults with speeds greatly in excess of 66 knots were being designed and should cater for all possible future requirements.

Prior to 1942 severe restrictions were placed on the dimensions, weight and take-off conditions for Naval aircraft and it was his Department that suggested the removal of many of these restrictions as being quite unnecessary and an arbitrary handicap to the aircraft designer. As a result of the action taken by his predecessor, Sir Stanley Goodall, a special meeting of the Joint Technical Committee was called in December 1942 at which aircraft designers were present. The whole object of the meeting was to remove, or modify as far as possible, the restrictions then imposed and as a result considerable changes were made in allowable length, folded width span, height, weight and take-off requirements. It was also agreed that when these revised limitations began to restrict or handicap the aircraft designer, a further meeting should be held to discuss the matter on the same lines. If any limiting dimensions or conditions now imposed by the Admiralty were a handicap to aircraft development, he would welcome a meeting with aircraft designers to discuss the matter. The ship designer must co-operate with the aircraft designer and must play his part in the joint effort. This had been the attitude of his Department for a long time.

As an example of the flexibility of aircraft carriers and their equipment, when *Implacable*, one of their latest Fleet carriers, was designed, the Naval aircraft in operation were Swordfish, Nimrods, and Ospreys, with the Albacore and Skua in the design stage. The requirement was that *Implacable* should be able to operate these aircraft. The *Implacable* had never carried any of these aircraft but instead, on commissioning and during the war, operated Avengers, Seafires and Fireflys. Only one of these types was really an aircraft designed for the Navy; the Seafire was an adapted or modified R.A.F. Spitfire and the Avenger was an American aircraft. A sister ship to the *Implacable* landed an R.A.F. Mosquito. The aircraft then flew off the deck and these operations were repeated several times. Similarly, a Vampire had landed on and flown off from H.M.S. *Ocean*, a light Fleet carrier. The fact that these two R.A.F. types were capable of being operated from aircraft carriers would seem to indicate that the limitations imposed on Naval aircraft were not necessarily restrictive.

No insuperable difficulty was foreseen in handling aircraft without undercarriages in an aircraft carrier and experiments to this end were in an advanced stage. There were bound to be certain difficulties but he had every confidence that they could be and would be solved, subject to possible compromises in certain directions.

**Admiral Sir Philip L. Vian**, K.C.B., K.B.E., D.S.O. (Fifth Sea Lord): How would Naval carrier aircraft get on when landing ashore without landing gear? They would probably have to land on shore more frequently than on the carrier.

**Mr. Farren:** He did not feel that it was at present possible to assert that a Naval aircraft without an undercarriage would have the same freedom to operate from shore bases as the normal aircraft. Nevertheless, the potential gain to the aircraft's effectiveness as a weapon was such that he believed it would be well worth while to pursue the development.

**Mr. D. L. Hollis Williams** (Chief Engineer, Fairey Aviation Co. Ltd., *Fellow*): In view

of the far-reaching developments taking place at the present time, one valuable line of discussion would be to get ideas on the "shape of things to come."

With the aerodynamic improvements necessary to cope with high Mach number effects, "sweeping" changes might be expected in the appearance of R.A.F. aircraft. Would these changes also follow into the Naval field as had been the case in the past? Would Naval aircraft assume the heavily swept-back and possibly tailless configuration, or would they be forced to advance along present-day lines, because of operating limitations? Naval aircraft were faced with the problems of long duration, low approach speed and limited dimensions. Low drag configurations tended at the moment to generate low lift only and consequently involved large wing dimensions. Control on the approach was an important governing factor requiring powerful controls. It would seem, therefore, that the chances of tailless types for Naval aircraft would be delayed and that general configuration as they now knew it, with improved lift devices and with tail controls, would probably persist for some time.

The fundamental change in power plants was also having profound effect on design.

How did Mr. Farren make provision for flexibility as a basic design requirement? He had never designed for flexibility in the first instance, all efforts being concentrated on producing the best possible aeroplane to a particular requirement. What actually happened was that when this aircraft came into operation, the Services found that they could do more with it than they had anticipated and so, more loading schemes were devised and in due course more powerful engines became available, thus increasing performance and load capacity, and by a process of evolution flexibility was obtained. An aircraft that was designed for one particular task, thus progressed to do many tasks and so fitted into the general scheme of carrier operation, which demanded the minimum of types for the maximum number of duties.

**Rear Admiral M. S. Slattery,** C.B., R.N. (*Fellow*): Flexibility was one of the points which most interested him. Mr. Farren had said he though it a good thing if they built flexible aircraft. That sounded suspiciously like the trap that they had so often fallen into, which was trying to make the aircraft do too much, but Mr. Farren had made it clear later that if they applied those principles with judgment, they should not err by getting bad aeroplanes. That was important because they had produced a number of aircraft in the past which had not been as good as they might have been because they had tried to make them do everything from the start. The way to be quite certain of building flexible aircraft was by concentrating at the outset on building a *good* aeroplane. Why design to meet every possible requirement? By the time everyone had added the things he would like an aeroplane to carry they had a specification which it was well nigh impossible to meet.

Supposing the Mosquito had been designed in the first place to carry that tremendous variety of weapons which had been displayed, would they have got a Mosquito? Had the Lancaster been designed to carry the huge bomb would they have got a Lancaster? And had the Spitfire and the Hurricane been designed to carry bombs, would they have led the world as the finest fighters? They would not.

Those aeroplanes were probably among the most versatile because they were, first and foremost, good aeroplanes. Not one of those four aeroplanes was a Naval aircraft*

He was tired of hearing people talk about designing aircraft for ease of maintenance.

*Admiral Slattery added later that: In all fairness, the Swordfish should be included. This aircraft, which was largely a private venture, proved flexible. It carried a great variety of weapons and equipment, was greatly overloaded and was used for many purposes for which it was never designed. It should go down in history as a "good" aeroplane.

He did not want one which was easy to maintain; he required one which did not need maintaining. They had used American aircraft during the war and it was said that they were easy to maintain. That was not true. They were not easy to maintain, but they did not require maintenance. They would run, on the whole, with the absolute minimum of servicing. That he thought was due to the difference of the psychological approach of the American and the British to engineering. They could see it demonstrated in the motor car field. The American car lasted for 50 or 60 thousand miles and then was overhauled. Could they not have aeroplanes like that? That was a cardinal point in Naval aviation where in carriers they were short of accommodation and workshop facilities. They wanted aeroplanes that would run for a reasonable time with the absolute minimum of maintenance and they wanted a reasonably robust aeroplane. In the design of machines they must keep all factors balanced and they had to keep strength somewhere in the picture in its right proportion.

**Mr. A. Davenport** (Technical Director, Westland Aircraft, *Fellow*): The first speaker had, he understood, suggested that certain restrictions on wing folding were being removed. He thought all design people would hope for that.

The following figures were taken from a machine which had recently flown:— with 18 ft. folded width the increased weight due to the folding and power mechanism was no less than 500 lb.; 400 on the structure and 100 on the power folding. The undercarriage increased 100 lb. in weight because of the longer travel etc., necessary to design an undercarriage satisfactory for deck work. This 600 lb. entailed a further 200 lb. on the main structure of the aeroplane, required in order to carry the increased weight and there was, in addition, another 100 lb. because of having to carry more fuel for altered cruising, making a total of 900 lb., which was 5 per cent. of the whole weight of the aircraft. That, he thought, showed the importance of having no fold at all if possible.

If the folded width was increased from 18 ft. to 25 ft. an immediate saving of 100 lb. was effected, which was an indication of the effect of such a change.

He was glad to hear the suggestion of eliminating the undercarriage altogether, especially from Naval deck-landing aircraft. It would give more room for fuel and there would be improved aerodynamic efficiency which would give the Navy an aircraft which could beat the land-based type.

If the folded width of an aircraft was increased they could reduce the weight of the structure, due to folding, save on the rest of the aircraft main structure weight, save fuel for duration, increase performance and, what was also important, reduce the size of the aircraft; and as cost was proportional to weight, they would save money.

THE ROYAL AERONAUTICAL SOCIETY

# NAVAL AIRCRAFT AND CARRIER EQUIPMENT

*by*

**L. BODDINGTON**

*Mr. Boddington studied Engineering at the University College and Technical College of Cardiff, obtaining the joint Diploma of both Colleges and the Sir Edward Nicholl Scholarship. From* 1931-1936 *he was assistant to Major H. N. Wylie and joined the Royal Aircraft Establishment in* 1936, *working in the Catapult Section. In* 1938 *he took charge of this Section, which ultimately grew to form the Naval Aircraft Department in* 1945. *He was Superintendent of the R.A.E. Design Office from* 1942-1945, *and since May* 1945 *has been head of the Naval Aircraft Department.*

## 1. INTRODUCTION.

THERE are a number of essential differences between aircraft designed to operate from carriers and those designed to operate solely from land bases. Some of the features are detrimental to good structural weight and even to aerodynamic performance, and involve both the aircraft and carrier in special equipment.

Of these features the two most important are assisted take-off and deck landing. Assisted take-off includes catapulting, accelerating and rocket assistance; landing involves arresting and safety-barriers.

It is now the practice to refer to all methods of mechanically-assisted take-off as catapulting, to bring it into line with American terminology. Until recently, catapulting denoted a particular method of launching whereby the aircraft was supported entirely on a cradle with no part of the airframe in contact with the ship structure, and such equipment was installed in ships with no flight deck. Accelerating denoted that the aircraft was launched along the deck on its own undercarriage which gave it some degree of support. Accelerating was peculiar to ships with flight decks, *i.e.* carriers.

I do not propose to describe equipment in engineering detail, but have confined my paper to the methods of meeting the staff requirements and the problems peculiar to them.

## 2. CATAPULTING.

### 2.1. DEVELOPMENT TO PRESENT DAY.

Before embarking on a logical discussion of present-day practice, it is necessary to refer briefly to a few details in the history of catapulting.

Professor Langley used the catapult to launch his glider across the Potomac in 1903, and the Wright Brothers used it to give the necessary initial flying speed to the aeroplanes constructed and flown by them, in America.

The naval authorities in America were the first to appreciate the possibilities of catapulting and they successfully launched an aircraft from a wharf installation in November 1912. The speed of 40 knots was obtained with an acceleration of 2.3g. A launch at sea from a barge was effected in November 1914 and catapulting was introduced into the normal routine training of pilots. By 1916, America had fitted a few cruisers with catapults and to avoid the ship having to steer a specific course to launch the aircraft into the wind, turntable types were introduced. Entry of the U.S. into the 1914-18 War caused these catapults to be removed.

The experience of the war showed a need for catapults for operating aircraft from battleships and development and provision were such that 32 catapults were installed in ships by 1925, with shore installations for experiment and training. Little advance was made in the performance; a launching speed of 38 knots was obtained with a mean acceleration of 2½g. Up to this era, the cradle which supported the aircraft was thrown away at each launch, but by this time it had become an integral part of the catapult and was brought to rest by a deceleration of 20g.

In this country it was not until 1916 that any action was taken to develop the catapult. On the knowledge of the American developments a specification was issued to deal with a weight of 5,500 lb. at 53.5 knots and 2½g. acceleration in a distance of 60 ft.

Two designs were tested but the Armistice curtailed the work, which was not restarted until 1922. Two designs were ordered, resulting in the Carey type and the R.A.E. telescopic ram type.

The Carey type, built at Chatham, followed the American principles but introduced a different method of retarding the cradle and catapult mechanism. Installed in H.M.S. *Vindictive* in 1925, the first flight was made by Squadron Leader Burling on October 30th in a Fairey IIID. The performance of the catapult was 40 knots, with a mean acceleration of 2g.

The R.A.E. catapult had the same performance, but introduced an entirely new principle. It was installed at R.A.E. on Jersey Brow, and remained there for experimental work until 1939. A few were fitted in battleships.

Other types, with variations of the rope system, were developed but the Carey type proved to have many advantages and the catapults used in service were based on this principle.

During these years there was developed, by Farnborough, the universal cradle and the technique of cross-wind launching. This dictated the method of catapulting and has influenced the methods of accelerating up to the present day.

Catapults were removed from battleships in the early part of the late war and, except for the use of the C.A.M. ships, which carried the R.A.E. rocket catapult and which operated in the Atlantic gap and on convoy duty, all effort was concentrated on the carrier problems.

In 1920 the aircraft carrier *Langley* was fitted with two catapults of long stroke and low acceleration—the forerunner of the "accelerator." In this country the accelerator was first fitted to H.M.S. *Courageous* about 1933, the trolley embodying the principles of the universal cradle. It had serious disadvantages, particularly for rapid loading and in 1937 fresh staff requirements were stated to meet the new carriers under construction, aiming at high rates of launching.

Experiments were made at Farnborough on four possible methods to meet a basic requirement, that the aircraft must be capable of being launched from a position up to 18 in. off centre. Early requirements favoured lower accelerations, but ship construction and flight deck operations dictated a maximum run of 96 ft. The launching speed required was 66 knots, giving a mean acceleration of 2g. Meanwhile, loading experiments made on the deck of H.M.S. *Argus* demonstrated that with guide boards, the aircraft could be lined up within 3 in.

Two methods were developed which satisfied the requirements. The first involved a trolley which engaged the catapult spools on the aircraft and the other, a towing method which involved special hooks. At this time, the need to catapult aircraft from battleships was still a requirement and as the extra weight on the aircraft to cater for two methods of launching could not be tolerated, the trolley method was developed.

To-day, both methods are in service, but the towing method is now the accepted method of catapulting aircraft from the decks of carriers and the trolley method is obsolescent.

### 2.2. Trolley method of catapulting.

Accelerators, or catapults as they are now called, are fitted to the forward end of the flight deck. Their function is to launch aircraft in circumstances under which they could not fly off, such as in a cross-wind or where a large deck range has to be flown off, and where there is insufficient deck space or when landing operations are in progress and the deck is divided by the barriers. The trolley method is still used in conjunction with the Firefly and the Barracuda.

The trolley base consists of three sliders and their coupling bars to form an articulated link in the rope system. The horizontal force is transmitted to the aircraft front spools by the front hooks, which are towed by adjustable cables from the front cable anchorage mounted on the leading slider. The front legs which carry the hooks are mounted on the middle slider and the rear legs, designed to take vertical loads only, are mounted on the aft slider.

The front hooks are free to rise about 3 in. in the leg tube. During the early part of the launch, the hooks sit down solid on the leg tubes to take the component of the towing rope forces and the weight of the aircraft is carried mainly on its undercarriage. As speed increases and aerodynamic lift tends to relieve the undercarriage of this load, the hooks extend. At the end of the launch the legs collapse under the control of oleo members to clear the aircraft.

In the first installations the trolley was mounted in a single track, but after experience in service it was considered an advantage to provide a wide base and a twin-track system was adopted for the light fleet carriers.

In developing this method it was originally intended to launch at a much greater incidence than was the practice in catapulting, but to provide clearance for stores and so on, it was necessary to retain the 4° incidence which demanded the long slender rear legs and a new loading on method. In previous accelerators, the tail was lifted by a jack in the deck.

The trolley is non-rigid until the aircraft is loaded on. The aircraft is taxied into position against the chocks and centred by the guide boards. The trolley is then drawn back. Each leg can be handled independently. The trolley is manœuvred forward and the rear leg is engaged on the rear spool. (There is one worker on each leg.) Continued motion of the trolley forward forces the tail of the aircraft to rise—forward motion of the aircraft being resisted by the chocks. At the proper time the front leg worker engages the front spools with the hooks extended, and as the legs move into the vertical position a detent bolt is pushed in front of the front spool. When loaded, the tow ropes are just taut and the front legs locked against falling forward. The detents take the airscrew thrust prior to the launch and the legs are unlocked after the first 6 ft. travel of the trolley. A well-trained crew could work to a launching interval of 40-60 seconds.

The twin-track trolley introduced new features which obviated unshipping the gear from the track when the deck was required for normal take-off, but in principle it was identical with the first single track type; it was less cumbersome for the leg workers to handle.

### 2.3. Towing method of catapulting.

The early experiments at Farnborough showed that the most economical method of loading was by towing the aircraft along the deck by wire bridles, provided that the towing points on the aircraft were positioned relative to the C.G. so as to avoid pitching move-

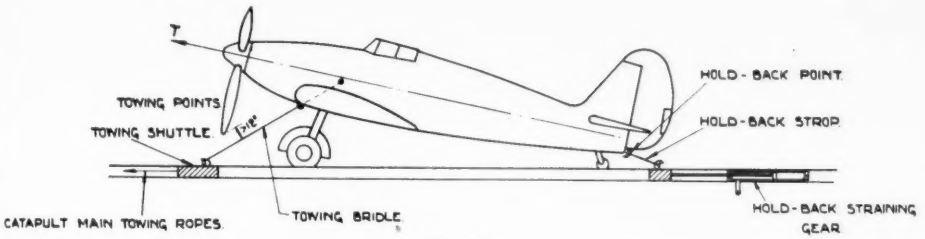



Fig. 1.
Diagram of tail-down method of launching.

ments and heavy tail (or nose) wheel loads. But it was not until American equipment was operated by the Royal Navy that this method of launching became a requirement. Experiments proved that British aircraft could be adopted for this type of launching, despite the fact that British undercarriages were reputed to be designed to less stringent requirements.

This is now called the "tail-down" method, but the introduction of nose-wheel aircraft may force a change of title. It is illustrated diagrammatically by Fig. 1, and present installations provide for towing either from a single hook running in a single track system, or two hooks from a twin-track. Fig. 2 illustrates the first, and Fig. 3 shows the Sea Hornet with a twin bridle. The application to nose-wheel aircraft is shown by the experimental installation on the Airacobra (Fig. 4).

The hooks (or hook) on the aircraft are attached to the towing hook on the deck by a steel wire-rope bridle. The aircraft is held back against airscrew thrust by a "hold-back" link which engages a suitable fitting at the rear of the fuselage (for tail-wheel aircraft), and is anchored to the deck. The system is tensioned through the hold-back link to a predetermined load prior to full take-off thrust. Under this thrust, the aircraft strains forward and tends to slacken the tow rope. The initial tension must be such that it remains tensioned to some degree to avoid slack and therefore snatch loads on launching.

The launch is started as soon as the accelerating forces, applied through the deck hook, are sufficient to rupture the breaking link in the hold-back unit.

Getting the aircraft in position is much simpler with this method, as there is no obstruction by trolleys on the deck. The operation is illustrated diagrammatically in Fig. 5. The aircraft approaches obliquely, the starboard main undercarriage wheel engages the guide board and the aircraft, still under taxying power, swings straight. A tail board prevents the tail wheel over-swinging the centre line, and the aircraft runs forward against its chocks in a central position.

### 2.4. The Aircraft Equipment.

The accelerating loads are provided through a pair of hooks disposed so that the towing forces act through, or close to, the C.G. under static conditions. The hooks project sufficiently to engage the tow rope eye, and it is questionable whether this projection warrants the elaboration of retracting mechanism.

The hook must be disposed in the line of pull, but the beak must face directly aft to give a clean pull away of the bridle on release of the aircraft.

The fitting to engage the hold-back consists of a shackle or tongue, and is designed to cater for break-away loads of 1.5 times the sum of the maximum thrust plus 1,000 lb. (or .1$W$ whichever is the greater). This works out to load of approximately $W$, and on the break-away results in an immediate application of 1g acceleration.

Fig. 2.
Tail-down launching with single strop—Wildcat.

Fig. 3.
Tail-down launching with twin strops—Sea Hornet.

Fig 4.
Tail-down launching—tricycle—Airacobra.

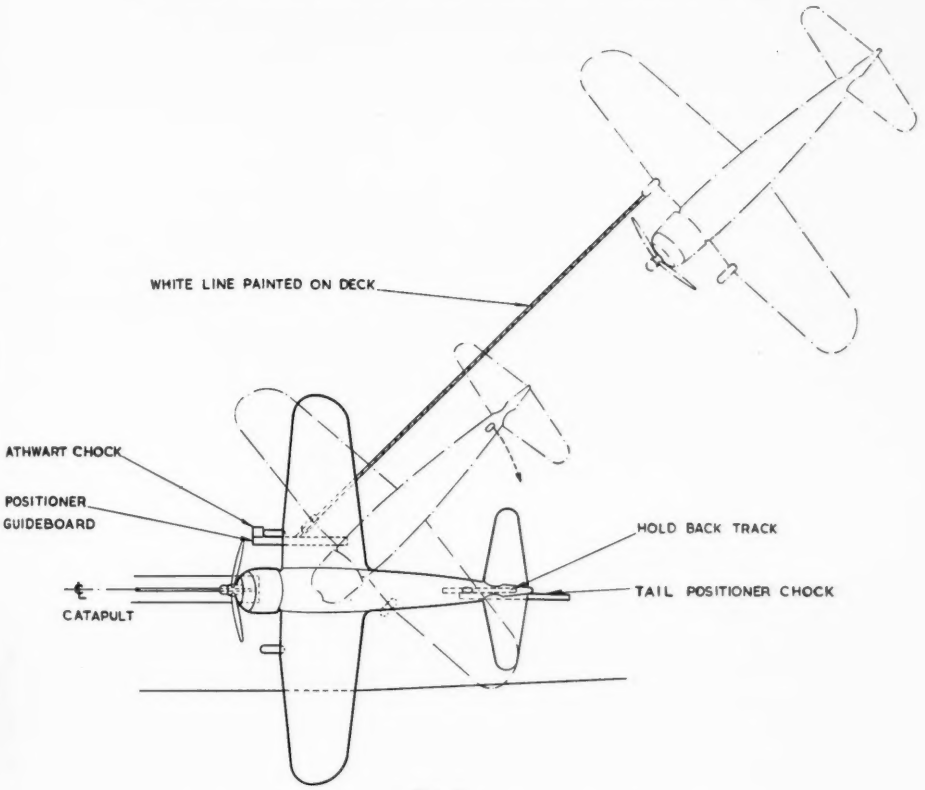



Fig. 5.
Diagram of method of positioning aircraft for tail-down launching.

Careful attention must be given at the design stage to the angle, both of the towing bridle and the hold-back link, to keep the undercarriage loads within the normal design requirements.

### 2.5. Deck equipment.

Equipment which provides the link or connection between the aircraft comes into this category.

The towing bridles, which are expendable items, are made from the appropriate size of 7/37 construction extra flexible wire rope. They are formed as a spliced grommet and seized to give two towing eyes and two rope sections in each leg of the bridle.

The weakest point in the bridle is the towing eye, which is considerably aggravated by the need to keep the hooks on the aircraft as small as possible. Further, the eye is subjected to severe hammering on the deck when the aircraft is released and the bridle brought to rest.

Initially, the eyes were bound with serving wire and this retained the strands in position and increased the breaking load to about 75 per cent. of the aggregate breaking load of the ropes. On smaller ropes and under experimental conditions, it was found that the strength could be fully recovered by swaging a tube on to the rope and bending it to shape. Difficulties in production, however, reduced this to about 77 per cent., and as damage to the eye made further use of the bridle unsafe,

the served eye has been reintroduced. The life of the bridle is increased as the serving can be removed to inspect the rope at the eye and re-served for further use. Each aircraft has its own bridle. The diameter of the bight at the deck hook can be made large to obviate these difficulties.

The American type of break-away link is generally in use and is illustrated in Fig. 6.

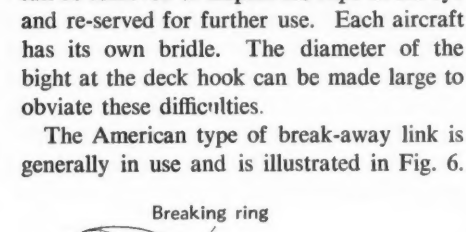



Fig. 6.
Diagram of hold-back break-away unit.

The swivel hook is retained in position by a breaking ring which is designed to suit each aircraft. The latest American practice is to fix the break-away loads and design the aircraft to suit. The second type is known as the wedge type. The break-away is effected by wedging open two jaws against an encompassing ring. The position of this ring on the jaws relative to their hinge determines the break-away load. One size ring only is required. The rings are manufactured to fine limits and rigid tests enforced to ensure uniformity of breaking load.

The hold-back link engages the hold-back rack set flush in the deck. This rack can be manœuvred under hydraulic control to provide the hold-back conditions required.

The deck equipment is completed by the guide boards referred to before.

### 2.6. Under-deck machinery.

The early Carey catapult imparted the accelerating forces to the trolley through a multi-reeve rope-pulley system from a power ram-cylinder unit. Although there has been considerable progress in detail design and performance has been increased, the same principle is embodied in the catapult machinery now used.

In early catapults, energy for launching was obtained from cordite charges, but in view of the need for short time intervals between launches, this source of energy was not practicable for the accelerator. It is interesting that on an experimental equipment installed at Farnborough, launching intervals of one minute were obtained from a cordite-operated accelerator. Compressed air is the energy medium now used with hydraulic control on the front side of the piston.

A diagrammatic layout of the accelerator is shown in Fig. 7. Compressed air acts

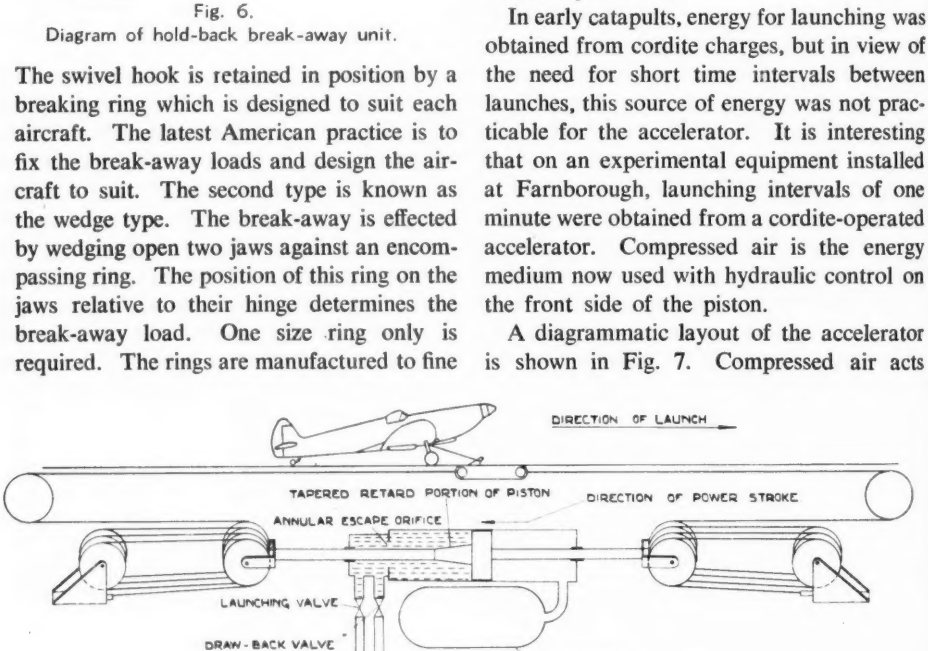



Fig. 7.
Diagram arrangement of hydro-pneumatic catapult.

directly on the power piston, the motion of which is controlled by the "leakage" of water from the annulus in front of it. This control is provided by a launching valve which is arranged to operate in a predetermined manner. It is a sluice valve type and it is opened under constant force against a dash-pot, the orifice of which is varied by the motion of the valve.

The forces are transmitted to the trolley or towing hook through an 8.1 reeved system, which includes means for tensioning the rope system.

The piston, ropes and trolley, are brought to rest by the "swollen" part of the piston rod in front of the piston passing through the choke ring and forcing water through a decreasing annular orifice formed by this choke ring and retardation profile. A similar 8.1 system is reeved to the rear of the trolley to bring it to rest after the launch.

High pressure air is stored in a number of air vessels, and by varying the pressure and number, the desired characteristics for weight and speed can be obtained. At the end of the launch the water is pumped back into the annulus and the air recompressed back into the bottles, and is therefore not expended. The rate of operation is dependent on the size of the pumping machinery.

As in most catapult machinery the biggest problem is bringing the moving parts, such as ropes, crossheads, trolley and so on, to rest from the launching speed. In the early catapult this had to be done as quickly as possible, so that the aircraft would clear the trolley.

In present-day accelerators, the retardation is effected by 21 ft. (compared with 96 ft. for acceleration), which gives mean retardation of 9.2g. and a probable maximum of 12g.

With the towing method this is not so fundamental, as there is no launching superstructure to collapse rapidly to clear the aircraft, although the motion of the bridle is important.

The same fundamental differences still exist between British and American equipment. In the latter, retardation is effected by external buffers (similar to the railway hydraulic safety buffers) acting directly on the power piston and the air acts on the piston through hydraulic fluid. Little effort has been made to control the rate of build-up of effort.

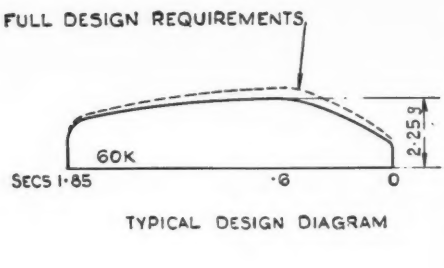
### 2.7. Acceleration characteristics.

The requirements for carrier catapults have been inherited from the early experiments, which gave a dropping value of acceleration towards the end of the launch. The terminal acceleration was the critical one for the aircraft designer, since it was coincident with lift and provided the heaviest loads on the rear spools. This characteristic was desirable in the early accelerators which embodied a rigid trolley.

The non-rigid trolley tended to reduce this effect but was still embarrassed by the position of the spools relative to the C.G. With the towing method it is more advantageous to apply the maximum acceleration at the end of the launch, as far as airframe design is concerned, keeping the launching run to a minimum.

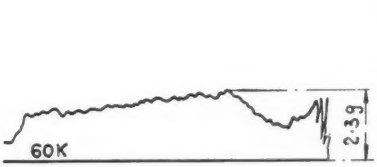
Design requirements, however, specify the maximum-mean acceleration ratio as 1.25, and with a mean acceleration of 2g. to give 66 knots in 96 ft. the maximum acceleration is 2.5g. The design requirements are shown in Fig. 8 with typical acceleration records taken from aircraft by both launching methods.

On British carriers the maximum build-up of acceleration takes place in approximately .6 seconds, but with American equipment this is of the order of .3 seconds. It has been found that after the aircraft breaks away from the hold-back, there is a drop in load transmitted to the towing hooks and that this depends on the weight and elasticity characteristics of both the aircraft and moving parts.




TYPICAL DESIGN DIAGRAM

TROLLEY




TAILDOWN

Fig. 8.
Design and typical acceleration diagrams.

The history of the effort of the power cylinder cannot be read directly into accelerations and the elasticity of the system is a critical factor, especially in the early stages of the launch.

Before the cylinder effort can be translated into towing effort, an oscillating effort has to be superimposed and the phase of the oscillating effort is such as to retard the initial build-up of the hook effort. The elastic system is complex and varies with each aircraft. The tendency is for the oscillating effort to increase with the size of the hold-back breaking load and to be affected by the characteristics of the undercarriage and airframe.

### 2.8. Undercarriage loads.

In addition to the loads due to weight, thrust, torque, lift and towing effort, the main undercarriage and tail wheel are subjected to dynamic loading caused by the rate of application of the vertical component of the bridle load and the load deflection characteristics of the undercarriage.

From the tests so far made, provided that bottoming does not occur the dynamic effects are not serious for .6 seconds build-up or critical for .3 seconds build-up.

The vertical velocity developed by the aircraft during the build-up is of the order of 2 f.s. The oleo-ing effect is small and the load deflection characteristics can be considered dependent on the tyre and air curves, with friction.

Under these conditions, inertia loading is imposed at engine mountings, tail wheel, and so on, corresponding to accelerations up to 1.7g. The effect of friction in the oleo legs is not marked on the main undercarriage but may have appreciable effects on the tail wheel. The line of pull of the towing rope relative to the C.G. has, within limits, little effect on the main undercarriage loads. The effects on the tail wheel are not so unimportant, greater dynamic effects being evident if the line of pull lies forward of the C.G. in the static condition.

Under operating conditions at sea there must be superimposed on these loads the effects of a pitching and rolling ship, side winds, and possibly helm. Operational experience is limited and a full investigation of these effects is in hand to determine the limitations from the airframe aspects.

### 2.9. Stability of aircraft during launch.

Large pitching effects are resisted by the deck reaction which are controlled within the strength of the airframe by correct relationship of the bridle line to the C.G. and its angle to the deck.

Such control in yaw is not so precise and in deciding the towing hook arrangements on the aircraft, full consideration must be given

to this aspect. In general, twin hooks provide this stability, which is greatly increased if the towing is done from twin deck hooks. Single hook installations, both with tail wheel and nose wheel aircraft, permit comparatively large yawing angles before the towing loads produce effective correcting moments. Further, it is not certain, on production variations alone, that the C.G. of the aircraft lies on the fore and aft line and a combination of weather cocking, side wind and too much rudder could produce disastrous results. To prevent this happening, rudder settings for the prevailing conditions must be established which may accentuate the tendency of the aircraft to swing at the take-off. A locked tail wheel will resist the drift of the tail but under ship conditions and a wet steel deck, the limiting friction may be small. Experiments are at present in hand to establish the effects in side winds, particularly from the port side. The conditions set up may provide a design condition for the rear fuselage under side load. The problem is much embarrassed by ship pitch and roll.

Little can be said of the nose wheel layout at this stage. If the nose wheel rests on a platform which is part of the deck towing hook, then no stability problems arise but strength requirements may still be important. This is a serious complication for deck operation and at Farnborough we consider that these possibilities should be avoided by using two hooks on the aircraft. Even so, the control which the nose wheel may exert on the launch is as yet an unknown factor. The few launches which we have made at Farnborough on the Airacobra indicated a definite drift of the nose wheel up to about 12 in. It is probably unfair, however, to quote this case as the nose wheel was stiff and had little or no castoring effect.

### 2.10. Physiological aspects.

The story would not be complete without commenting briefly on these aspects.

From the pilots' point of view the present accelerations in service, which are of the order of 3.25g. (*i.e.* catapult power plus aircraft power) cause no discomfort whatsoever. The accelerations are taken in the ideal manner and provided that a proper head rest, made adjustable to suit the variations in stature of the pilot, is provided, it would appear that we are, as yet, well below any physiological limitation. Pilots agree that the launch is much more comfortable when the build-up from break-away to maximum is of the order of 0.6 secs. compared with 0.3 secs. or less.

Crew positions, facing forward or aft, provided that there are proper supports, do not cause any embarrassment or anxiety.

Should accelerations increase, the first effects may be the flattening of the eye-ball and in some cases temporary blackout, caused by the drainage of blood from the eyes. These are of a transient nature, and the blackout would only occur with an occasional pilot.

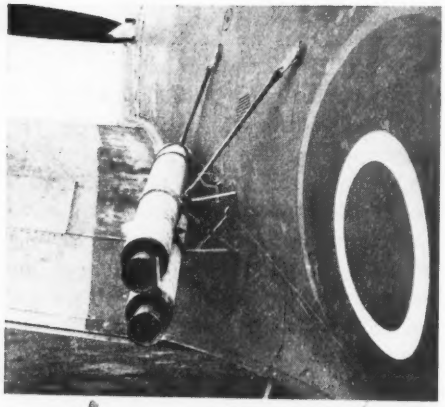
## 3. ROCKET-ASSISTED TAKE-OFF.

### 3.1. Introduction.

Rocket-assisted take-off, or R.A.T.O. as it is now known, has been essentially a recent wartime development in this country, although it is by no means a new idea. In 1928, Mr. Salmon, at Farnborough, worked on this problem and his investigations, which have recently come to light, show that if the idea had been proceeded with then, R.A.T.O. would have been accomplished before 1941.

Considerable effort has been applied to this problem in Germany and the Americans have developed a wider application to take-off from land and sea.

I propose to confine my comment to the Naval applications. Initial work was undertaken at Farnborough when an experiment on a Shark aircraft proved successful in 1941, using the standard 3 in. rocket projectile



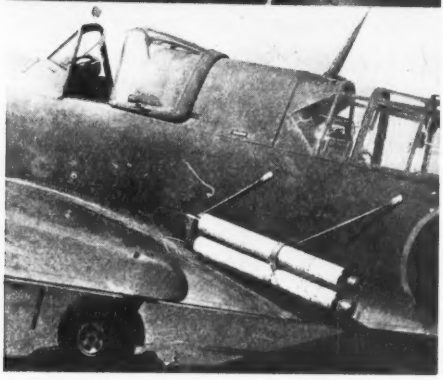


Fig. 9 (above).
Typical R.A.T.O. installation—rear view.
Fig. 10 (below).
Typical R.A.T.O. installation—side view.

motor then in service and giving an average thrust of 1,800 lb. for 1.2 seconds.

The present 5 in. motor, designed specifically for Naval use, was first introduced on the Swordfish in 1943.

### 3.2. Operational requirements.

R.A.T.O. is an optional way of developing take-off speed in a shorter distance, but unlike catapulting—and like free take-off—it must be done into wind. The primary need for this method of take-off was dictated by the converted merchant ship escort carrier where the length of deck was restricted and when a ranged strike left little space for free take-off. The inability of these ships to create the necessary wind speed over the decks was also a deciding factor.

Now, all naval aircraft are required to be equipped for R.A.T.O. and the basic requirements specify take-off in 250 ft. in a 20 knot wind against a free take-off of 450 ft. in a 27 knot wind.

It is necessary that the wings can be folded and unfolded with the rockets in position and to be able to load or unload them when the wings are folded. The installation must be jettisonable after take-off.

### 3.3. Aircraft installation.

In general the rockets are disposed in two groups, one on each side of the fuselage. In side elevation the thrust line should not be above the C.G. or be more than 12 in. below it. In plan view the thrust line should lie in as close as possible to reduce the yawing movements to be expected should one or more of the rockets on one side fail to ignite. Longitudinal C.G. movement caused by the weight of the installation must not adversely affect stability, although as the rocket installation is normally jettisoned soon after take-off, this is not usually an important point.

The rockets are fired electrically, the cockpit control consisting of a master switch on the instrument panel and a firing button on the throttle. A test and distribution box is mounted in a convenient position. The electrical lead from each rocket terminates in a plug which engages a socket fixed in the side of the fuselage.

A typical installation is shown in Fig. 9 and a close-up view of a group assembly in Fig. 10. The cradles are designed to suit each aircraft and can carry rocket motors up to the maximum numbers for which provision is made.

The thrust is transmitted to the aircraft through a single fitting on a strong point of the airframe and the cradle is stabilised by light members in the region of the rockets.

Jettisoning is effected by a release catch of the bomb slip type and arrangements may be

necessary to control the motion of the cradle immediately after release, to clear the airframe or the tail of a torpedo. The installation is expendable; the rocket tubes could not be used again.

### 3.4. The rocket motor.

The use of the 3 in. R.P. with only a burning time of 1.2 seconds involved sequence firing to provide the thrust for the length of time required, about 4 seconds.

The need for a unit with a burning time of 4 seconds resulted in the development of the present 5 in. motor. It is approximately 4 ft. long and weighs 65 lb. before firing and 40 lb. afterwards. One end of the rocket terminates in a venturi-shaped nozzle through which the products of combustion are ejected and the other end in a fitting which attaches the rocket to the cradle and transmits the thrust.

Nozzle sizes are chosen to suit three conditions—Arctic ( – 5°F. to 65°F.), Temperate (30°F. to 90°F.) and Tropical (65°F. to 120°F.)—and are fitted to suit the conditions prior to the loading of the motors on the aircraft.

The limits of burning time are 3.7 seconds to 4.7 seconds depending on the temperature, the longer time occurring under the colder conditions. The total impulse is about 4,600 lb. sec. with a performance index about 180 lb. sec./lb. For calculating take-off performance a constant thrust of 1,150 lb. for 4 seconds is generally assumed. The first approximation of the number required is the next even number based on one rocket per 7,000 lb. weight. A typical thrust curve is shown in Fig. 11. Initial burning characteristics give a high initial thrust and this requires the airframe to be strengthened to a greater degree. It is a rocket design requirement that the thrust should be as uniform as possible.

The region of the rocket jet has been explored. The cone of the jet includes an angle of 26° and in general all parts of the airframe must lie at least 12 in. outside this boundary.

Blast pressures from the jet have been measured and show that they alternate, near the jet, in pressure and suction waves fluctuating with a frequency between 600 and 7,000 c.p.s. The mean of the positive

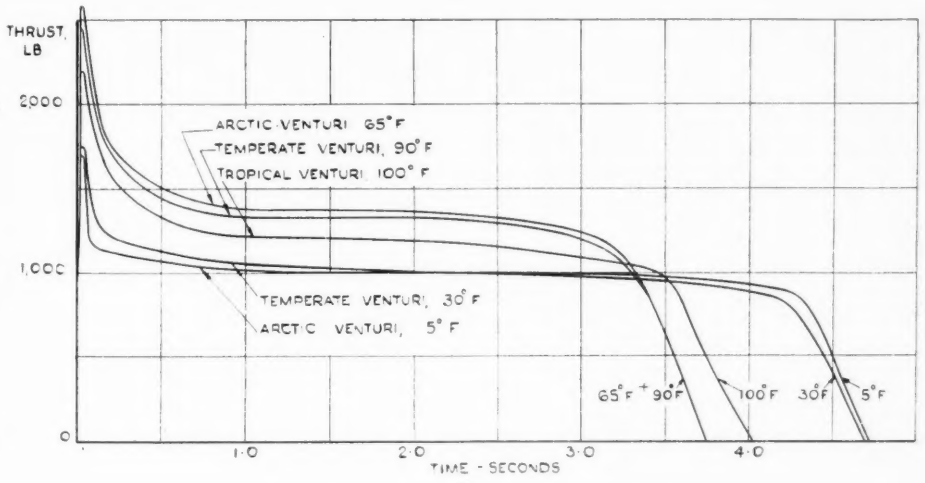



Fig. 11.
R.A.T.O. motor thrust characteristics.

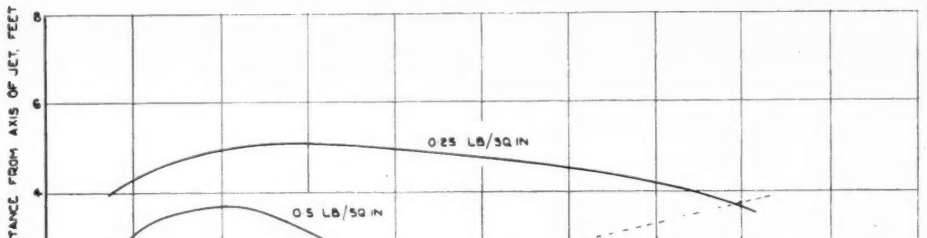

RADIAL DISTANCE FROM AXIS OF JET, FEET
0·25 LB/SQ IN
0·5 LB/SQ IN
0·75 LB/SQ IN
1·0 LB/SQ IN
ASSUMED SPREAD OF JET
DISTANCE ALONG AXIS OF JET, FEET

Fig. 12.
Mean positive blast pressures in the region of the jet.

pressures are shown plotted in Fig. 12 and suggest that the strength of the adjacent skin should be checked. For 2, 3 or 4 rockets, the resultant pressures should be taken respectively 1.6, 2.0 and 2.3 times one rocket.

### 3.5. Take-off procedure and performance.

The procedure involves a complete check of the electrical circuits just prior to take-off. In operation, the pilot starts his run in the normal way and at a speed of about 40 f.p.s. (24 knots) (interpreted to the pilot in terms of distance), the rockets are fired. The point of firing of the rockets depends upon the take-off speed and distance available, as it is imperative that the rockets should not fade out before take-off speed is reached. It is desirable that they should continue to burn for a time after the aircraft is airborne. In contrast to a normal free take-off the pilot makes no attempt to get the tail up and a better take-off will result if the tail is kept down throughout the run.

Figure 13 shows the curves of minimum take-off for a $2 \times 2$ rocket (*i.e.* 2 rockets per side) and $2 \times 1$ rocket installation on an aircraft of 13,000 A.U.W. For comparison, the free take-off distances are also shown. Superimposed on the diagram are the curves of minimum firing distances. The distances of take-off are a minimum and for operational conditions an allowance of 50 ft. on top of these should be added to cover for errors in firing and possible failure of one rocket, although rocket failures occur rarely in practice.

## 4. ARRESTING.

### 4.1. Introduction.

In the first landings on a carrier, no assistance was given to landing. To prevent the aircraft floating or drifting, longitudinal wires were introduced, which engaged hooks on the undercarriage and held the aircraft down. The first attempt to provide mechanical resistance to the aircraft was tried in conjunction with these wires. A series of athwartship flaps was erected in the way of the landing and the aircraft pushed them down.

The first attempt to use the athwartship wire was in 1922-23 when an aircraft was arrested by an inertia system. Multiple cross-wires were attached to sandbags and retardation forces were developed by inertia and friction effects.

The first real attempt at mechanical control of the forces was made on an experimental

installation at Farnborough in 1930. The transverse wire was taken at each end to a brake drum and in the first efforts the breaking loads were applied manually. Hydraulic brakes interconnected on both drums for simultaneous application were finally fitted to H.M.S. *Courageous* and tested in 1931.

The experiments at Farnborough showed that the position of the hook on the aircraft was important and before successful arresting could be accomplished, the hook suspension had to be modified so that the forces were applied farther aft and more in line with the C.G. The choice of suspension point was dictated by the strength of the fuselage at the rear catapulting spools. The modification made on the experimental aircraft merely arranged for the hook to be retained in a snap gear after picking up the arrester wire. Considerable pitching still obtained but the aircraft did not go over on its nose.

The characteristics of the *Courageous* gear, combined with the pitching performance of the aircraft, caused new requirements. Although the aircraft did not go over on its nose and the cropping of the propellers had not arisen, the tail was left high in the air at the end of the run-out and the subsequent drop on to the deck—tail slam—invariably caused broken tail skids.

The main requirement which dictated the design of arrester gear at present in service, was a reduction of the retarding effort towards the end of the run in order that the aircraft tail might settle gently on the deck.

The first of the present designs were installed in H.M.S. *Courageous* and tested in 1933. The fundamental principle introduced the retarding effort as a function of the velocity of the aircraft.

Under peace-time conditions, the arrester gears were not fully taxed and as they functioned satisfactorily, no close investigation was made into the characteristics or idiosyncrasies of the system.

The next important step was the introduction of double reeving in 1939. Up to then, one resistance unit served one arrester wire. By taking the "dead" fall on the reeve and leading it through suitable guide sheaves across the deck and introducing a centre span, a second wire was created. One wire picked up caused the other to act as the "dead" fall, but under these conditions free fleeting of the ropes through the system was removed.

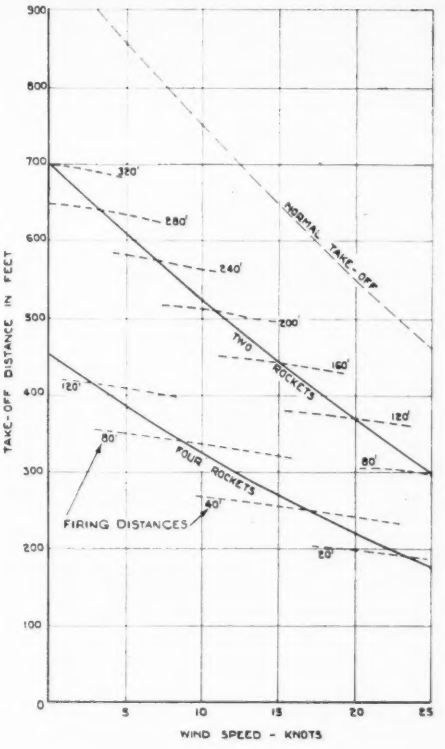



Fig. 13.
R.A.T.O. take-off curves for 13,000 lb. A.U.W. aircraft.

Hook installations on aircraft made progress only in detail design. The early experiments focused attention on snap-gears. All installations were of the A-frame type, generally hanging from the region of the rear catapult spools, making it imperative that snap-gear should be fitted. Tail-slam was

avoided by the decaying resistance, but pitching persisted.

Hook design centred on a narrow throat to prevent the rope fleeting through it. Many types of hook had been tried, including ejection of arrester wire at the end of the run. As with the gears, the aircraft was not taxed in deck landing and the problems and difficulties only became evident under conditions of war, particularly the hook-rope relationship.

Intensive investigations and researches were made at Farnborough in conjunction with D.N.C., who is responsible for arrester gear design, and this work has led to greater understanding of the functioning of the arrester gear, the mechanics of hook engagement and the design of hook installations.

The design requirements have remained at 1.5g. retardation during the whole of this period until recently, when the working retardation has been increased to 2.0g. to meet the needs of higher performance aircraft, since the limited deck space will not permit an increase in the arresting distance. Entry speeds have not yet changed in practice.

### 4.2. Deck landing.

A successful deck landing depends partly on the skill of the pilot and to a large extent on the suitability of the design of the aircraft for deck landing. The operation of landing can be divided into three phases, approach, touch-down and arresting. The first covers the stage right down to contact with the deck, the second the capabilities of the undercarriage and the third the arresting requirements. I do not propose to say much on the first two stages, except where the effects of arresting imposes additional loads or conditions on the airframe design. I would like to emphasise that there is one factor to which no technical or mathematical value can be placed, but which exercises a fundamental influence on a successful deck landing aircraft. Until good and unrestricted view of the deck is given to the pilot, the full benefits of the advances made in controllability in approach and airframe design, including undercarriages, will not be evident in accident statistics. Unless this is given proper place in nose-wheel aircraft, I forsee no significant reduction in the accident rate and such accidents may be of a more serious character. This is my personal opinion.

### 4.3. The deck equipment.

To an observer on the flight deck, the landing area consists of a number of arrester wires stretched across the deck. The wires are supported approximately 15 ft. on each side of the centre line, being 9 in. at the supports and about 4 in. at the deck centre line, dependent on the tension. The numbers of arrester wires vary with the ship design and as many as 12 may be provided to occupy the deck area aft of the barriers.

The arrester wires, made of 6/37 extra flexible steel ropes, are connected to the main reeving by simple pin couplings. These wires are generally referred to as centre spans and all render from sheaves, mounted directly on the deck edge.

The rope supports are spring bows of round section bar, clamped at the entry end and free to slide fore and aft at the forward end. They can be collapsed by an aircraft wheel running over them and will reset immediately. They can be held permanently collapsed by an air piston and cylinder operating directly on the centre of the span to pull it down on to the deck. The initial shape of the bow is such that it will collapse flat on the deck under this load.

British and American carriers are similar in the deck equipment and its layout.

### 4.4. Aircraft equipment.

The equipment on the aircraft comprises a hook suspension with means of stowing the hook in the up position and a pilot-operated

release. A force must be applied to the hook to cause it to trail at the required attitude and this unit may conveniently provide the resistance to bounce when the hook hits the deck or any projection on the deck, including the arrester wires.

Design requirements now require the hook installation to take working retardations of 2g. under the maximum landing weight conditions, the emergency landing at a higher weight being catered for by a factor of 2.

Originally there was only one type of installation, the V-frame type, in use on British aircraft, although experiments were made on the Skua with a single point suspension commonly referred to as a "sting" and ultimately adopted for the Firebrand.

Types of installations are shown in Fig. 14. It is impossible to put them in any order of preference and it should be emphasised that the installation must satisfy the particular aircraft both as regards design and pitching susceptibility. It is generally true to say that the hook suspension for tail-wheel aircraft should be as far aft as possible.

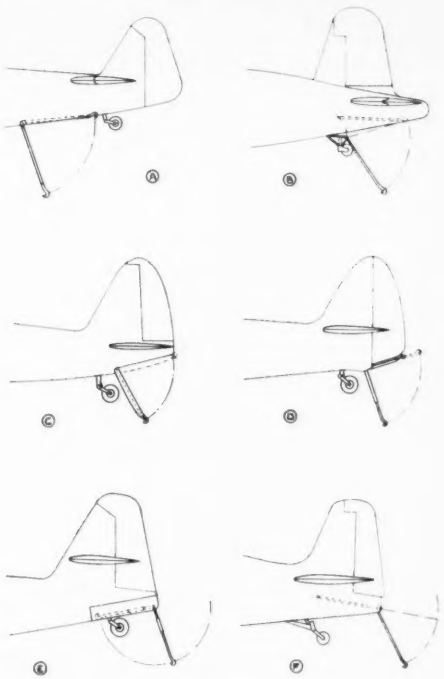


Fig. 14.
Types of arrester hook installations.

There are two forms of installation. The first, referred to as A- or V-frame, is restrained to swing in the vertical plane only. Side loads are either taken through the frame or transferred directly to the fuselage if a snap gear is used. The second form embodies a single shaft free to swing sideways as well as vertically, and to align itself with the forces exerted by the arrester wire. It varies in detail and to keep the suspension point as far aft as possible may introduce forward stowing, telescopic stowing or complete or partial retraction.

The damper, which acts with a small moment arm about the suspension point, has important functions. It must push the hook down to the required attitude against windage effects and must resist bounce and provide instantaneous follow-up forces to ensure certainty of engagement. Until recently, gravity has been the major source of follow-up force and the natural period of oscillation of the suspension in the gravity field has been such that the aircraft can progress over arrester wires before the hook returns to a position for engagement.

The pilot controls only the release of the hook. The snap gear type is self-stowing, the only point in its favour since other types have to be stowed manually. The only examples of retractable types are American, which can be stowed under pilot control when the rope is cleared. Hook down is indicated to the pilot by a tell-tale light in the cockpit.

The snap gear will receive the hook only if the rope is in the throat. The ejector lever is then pressed down and the anvil, which prevents the hook going up, is withdrawn and does not engage the stop. With the advent of the jet aircraft, pilot-operated release of the arrester wire and stowage will become an operational necessity.

### 4.5. Under-deck equipment.

In general, the layout of both British and American arrester gears are the same but the methods of developing the resistance differ.

Each pair of wires (seldom adjacent ones for operational safety), are reeved in a 12:1 rope system (10:1 in American systems) to a hydraulic ram and cylinder accommodated between the flight deck supporter beams. When an aircraft engages the arrester wire and pulls it out, the ram is closed up into the cylinder. The cylinder is full of fluid and pressure is developed in one of two ways:—

(a) In British equipment the ram, which carries a choke ring, moves over a fixed concentric tapered rod. The orifice formed by this rod and the choke ring, in conjunction with the speed of the ram, develops the hydraulic pressure.

(b) In American equipment, the fluid is expelled into a chamber by two passages. One is a fixed orifice set to suit the weight and speed of aircraft and the other a pressure regulating valve to limit the cylinder pressure to a certain value, also determined by the weight and speed of aircraft.

The equipment and rope reeving is shown diagrammatically in Fig. 15.

In both cases the liquid is expelled through a non-return valve into a pressurised vessel or air accumulator. To reset the gear, the non-return valve is by-passed or lifted and the air pressure forces the liquid back into the ram cylinder drawing back the deck span. The air pressure also maintains the nominal tension in the deck span and the rope system. Slackness is to be avoided or heavy snatch loads will result.

The main problem in the design of this equipment is to cater for the wide range of aircraft weights and speeds which a carrier is called upon to operate. Initially, the weight range was narrow but has now been much widened by the range of naval aircraft now operating. It is the heavy aircraft which controls the weight of the moving parts of the gear, yet all this weight has to be snatched into motion by the lightest aircraft, often combined with a higher entry speed. The moving weights must be as low as possible and the implications of the problem can be seen when an analysis is made of the equivalent weights of the system. The main reeving contributes 50 to 60 per cent., the sheaves 43 to 37 per cent. and the rams and fluid 7 to 3 per cent.

The British method has the advantage, from the airframe aspect, that practically the full stroke of the gear is used whatever the engaging speed of the aircraft. This run-out may be affected to the extent of 15 to 20 ft. by friction, accumulator pressure and aircraft drag and rolling resistance.

It is inevitable that the maximum weight of aircraft designs the tapered rod and as this cannot be adjusted or varied, it is necessary to provide a by-pass orifice for lighter weights. By mechanical complication this orifice could also be made variable during the stroke but at present it is a constant area set to suit the particular weight of aircraft operating. For the maximum weight it is closed. It follows that only at the maximum speed of engagement is the aircraft fully stressed, the retardation following roughly a $V^2$ law.

In the American method the retarding forces are controlled by a pressure regulator and the aircraft experiences the same retardation, irrespective of the entry speed, while the stopping distances become a function of the speed. This has an operational advantage on the flight deck.

### 4.6. Arrester gear performance.

The design of arrester gears is based on a basic retardation curve (Fig. 16) and by using the "sine" effect, *i.e.* the V formation on the wires during arresting, fluid flows and orifice sizes can be evaluated and the design is established. Experience has shown that

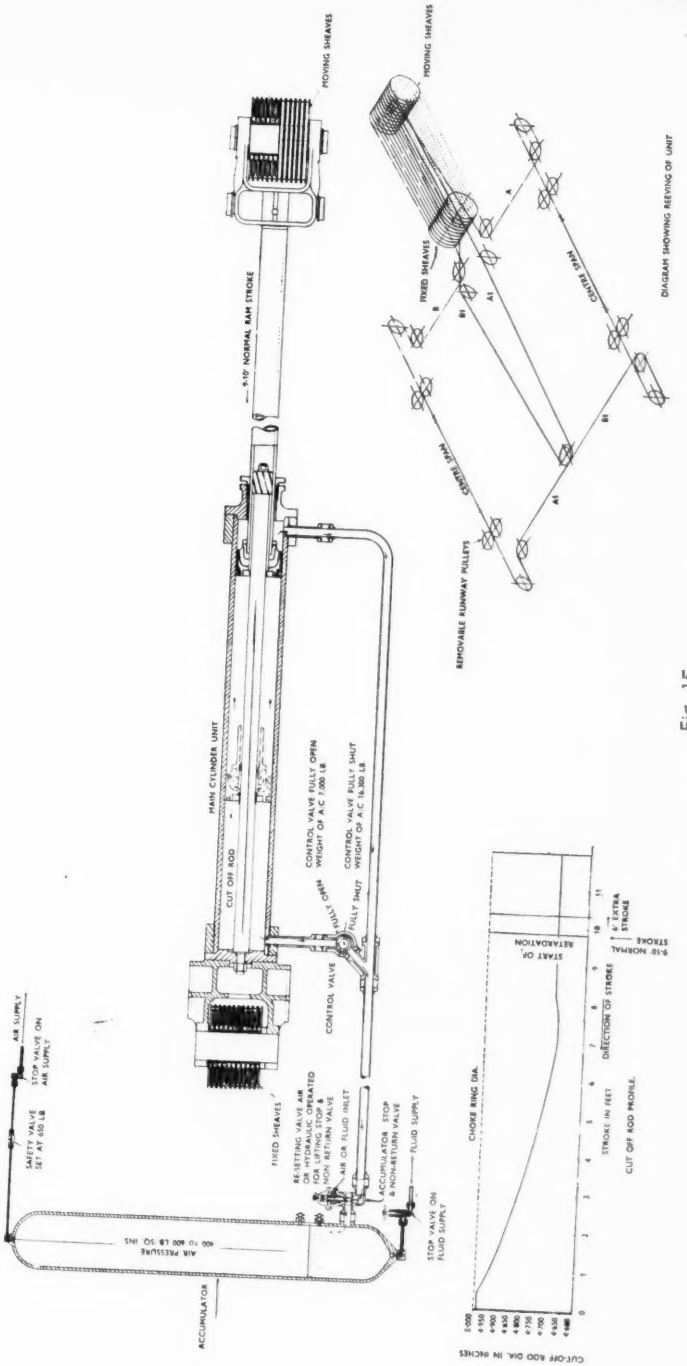



Fig. 15.
Diagram of British arrester gear system.

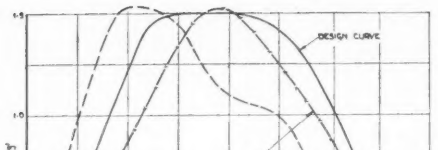



Fig. 16.
Basic and estimated retardation curves.

taking this design and assessing its characteristics may not bring one back to the basic retardation curve and adjustments have to be made, particularly to allow for inertia and impact effects. Certainly the design curve cannot be reproduced for all weights.

An attempt has been made to correlate the practical results with a purely theoretical solution to the problem. Up to the present it has been found satisfactory to superimpose the elasticity effects on the general investigation of the motion of the aircraft.

There are two inertia effects. The first is complex and is associated with the elasticity of the ropes and affects primarily the initial retardation characteristics by superimposing a fluctuating load on the general characteristics. The second involves the inertia of the moving parts assuming unelastic conditions, friction losses of the ropes running round pulleys and the effects on rope tensions under running conditions.

Comparison with actual measured results has led to the belief that the prediction of the retardation characteristics is reliable and sufficiently accurate. There is evidence that rope friction losses are not directly proportional to the rope tension, but in general the theoretical stopping distance works out slightly greater than the actual by 3 per cent. and the maximum retardation is generally about 10 per cent. less than the measured. These observations apply to weights and speeds up to the design requirements.

A comparison of the design curve and the theoretical curve is shown in Fig. 16.

Overloading of the arrester gear by receiving heavier aircraft may result in the gear coming to the end of its stroke and the piston bottoming before the aircraft has been brought to rest. This dictates the overload limit of the gear. Bottoming may result in the hook being torn out of the aircraft.

The calculated performance of a typical arrester gear with varying weights of aircraft and entry speeds is shown in Fig. 17. The rapid rise in retardation with the lower weights, caused by the inertia effects, will be noted.

Deck span is important in reducing inertia loads and variations exist in the performance of ship installations because of these differences, differences dictated by the flight deck arrangements.

### 4.7. The mechanics of pick-up.

The motion of the arrester hook for a fraction of time after engagement with a wire is complicated. The period of time is generally under 0.2 secs. with the result that the arrester gear has not come into operation.

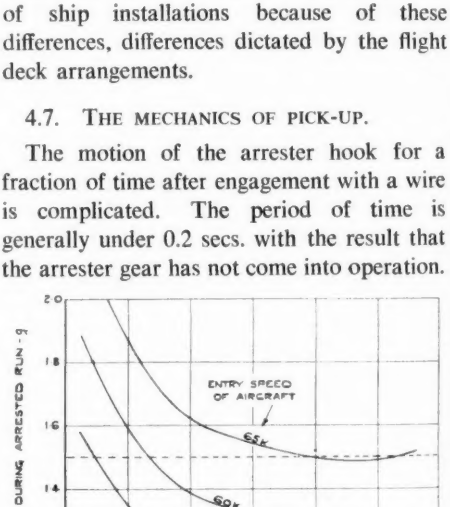



Fig. 17.
Maximum retardation against weight for varying entry speeds.

The theoretical investigation, while yielding no rigorous solution, does yield results which can be computed with observation and therefore are of value for design purposes. It provides a solution to the impact velocity of a hook in the snap gear or the maximum height to which the hook is thrown. No general recommendations can be made on the question of maximum angular velocity and clearance, except that the clearance angle measured above the horizontal increases with increase in moment of inertia. The maximum angular velocity does not necessarily represent the impact speed into the snap gear. Very high angular accelerations occur at the instant of pick-up and the hook suspension is subjected to inertia bending stresses.

Hook damping has a negligible effect after the engagement is made, but relief in a hydraulic system, where fitted, must be provided against high pressures.

One interesting feature, which will become more important if the speeds of entry increase, is the immediate formation of the arrester wire on impact by the hook. The impact sets up a wave of V formation with the hook at the apex. The angle at the apex remains constant, as does the stress induced in the rope, and the base of the V extends as the aircraft progresses until it meets the deck pulleys. Full reflection does not take place because of the yielding nature of the hydraulic gear. This phenomenon is shown in Fig. 18, where the induced V is clearly visible. It is discussed later in connection with the development of side loads.

Fig. 18.
Initial impact wave in arrester wire.

4.8. AIRCRAFT MOTION.

4.8.1. *Pitching susceptibility.*

During arresting, there are two features which must be avoided: (a) excessive pitching such that the propeller fouls the deck or deck equipment and (b) tail-slam, more evident with American type gear. The former is the more important.

This problem did not become important until the higher performance aircraft were introduced during the war, the conditions being aggravated by the reduced deck clearances.

The pitching motion should be predictable, but an examination of the problem has shown that this cannot be done with a high degree of accuracy, mainly because of the variety of attitudes and conditions the aircraft may be in at the point of engagement. Also, the surges in the arrester rope make it impossible to be precise on the direction of the applied forces. Slight variations in this affect the pitching appreciably.

In assessing the pitching susceptibility of an aircraft, the values given by an approximate mathematical method with its deficiencies are accepted on the assumption that these discrepancies, when applied to different aircraft, are similar. Hence the relative degree of pitching of one aircraft compared with another is assumed to be reasonably accurate.

It is, therefore, possible to draw up a list of aircraft in order of susceptibility to pitching and a second list in order of probability of the propeller fouling the deck.

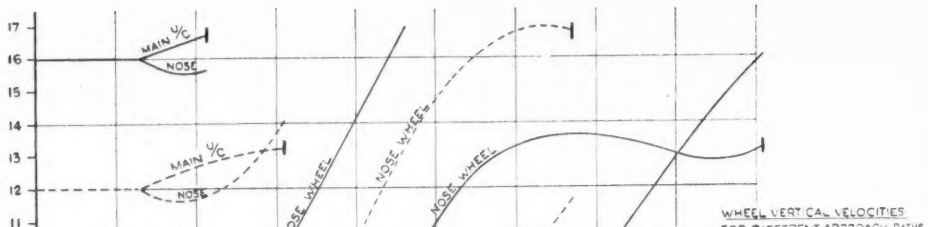



Fig. 19. Curves of contact velocities for nose-wheel aircraft

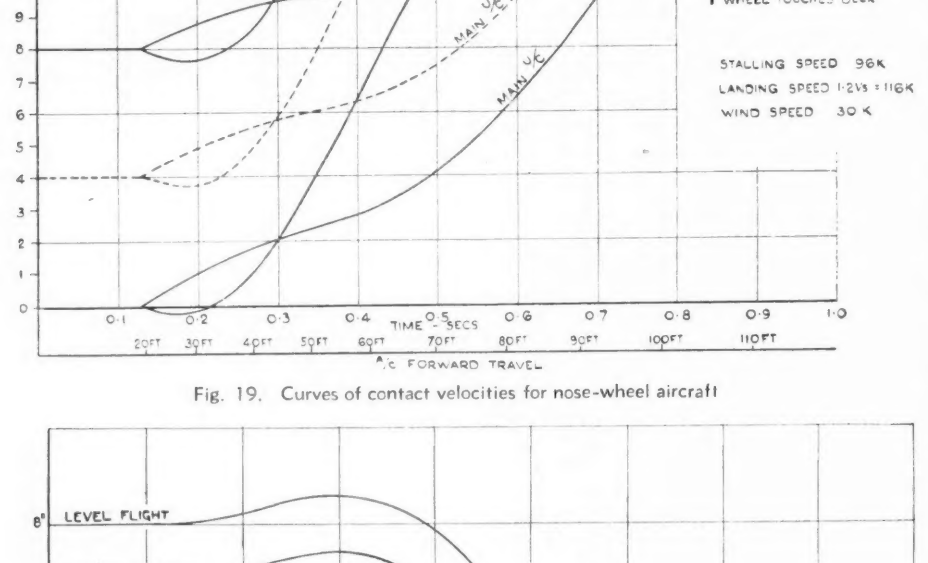



Fig. 20. Curves of incidence changes during arresting of nose-wheel aircraft

Applying this method to aircraft of known pitching performance, it shows that it is possible to anticipate the order of pitching of a new type in the design stage.

The pitching problem may be much more acute with nose-wheel aircraft and may be further aggravated by the landing technique adopted for jet aircraft.

Figures 19 and 20 show the results of an investigation into the probable contact velocities, both of the main undercarriage and nose-wheel, under assumed conditions of approach and the variations in attitude until contact is made with the deck. The curves indicate that if the aircraft picks up the wire in level flight, the nose wheel makes contact with the deck after .9 secs. at 13 ft./sec. The main undercarriage is still off the deck having a speed of 16 ft./sec. and the incidence of the aircraft is slightly nose down. At a sinking rate of 8 f.s. the main undercarriage makes contact with the deck at 10 f.s. in .45 secs., and the nose wheel then has a vertical velocity 16 ft./sec. with the datum 3.8° nose up. This investigation made on possible conditions, indicates strongly the need to consider in the early stages the position of the arrester hook on the aircraft.

On the Vampire, with the twin-boom layout, these effects were almost entirely absent because the hook suspension was so near to the C.G.

4.8.2. *Yawing and side loads.*

The development of side load and the consequent yawing of the aircraft is generally the result of off-centre landings, which can be aggravated by oblique entry or yawed approach.

Side load is developed in two stages, the first caused by tensions induced in the arrester wire by initial impact. This aspect is important in V-frame installations which rely on snap gears to take side load. It is essential that the V-frame should be rigid enough to withstand any side load effects during the short period of pick-up and that it should engage the snap gear satisfactorily. It has been found that the requirement of $W/8$ side load meets the present conditions satisfactorily. Such conditions operate for a short time interval before the hook has engaged the snap gear and do not have any material influence on the motion of the aircaft. The side loads which may be imposed on the hook under varying conditions of entry and hook friction are shown in Fig. 21.

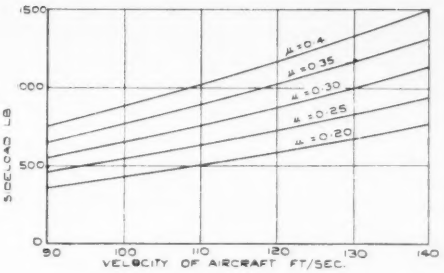



Fig. 21.
Side loads imposed on hook at initial impact, with varying friction.

The early design requirements for side load were specified as $W/8$ with an arresting force of $1.5W$. With non-fleeting installations, evidence showed that this did not cover the conditions when poor view made off-centre landings the rule and not the exception.

When an aircraft lands off-centre, the tail swings towards the centre line and the aircraft tends to track out-board. Under inertia effects it over-swings, straightens up and then tracks in-board. In plan view, therefore, there is a yawing oscillation and a slight snaking motion on the aircraft. During the run the side load will change from one side to the other, reducing to zero on the way. There may be three "zero" points in the run. Aircraft of low yawing inertia respond quickly to the side load components and a violent side kick of the tail in-board will be observed. It is almost axiomatic that the value of the side load increases with distance off-centre and reaches a value of one-eighth of the retarding forces at approximately 15 ft.

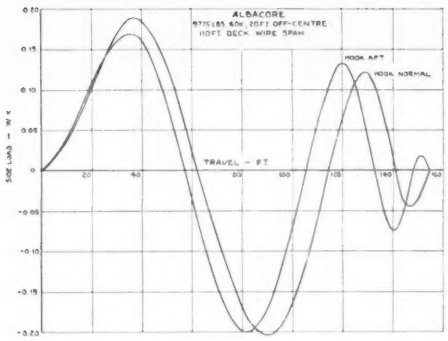



Fig. 22.
Development of side loads on Albacore during arresting off-centre.

for a heavy aircraft and 11 ft. for a light aircraft on normal spans.

The side load development on an Albacore has been investigated, using a deck span of 110 ft. and the results are shown in Fig. 22 for two positions of the hook, normal and 7 ft. farther aft. The motion of the aircraft is shown in Fig. 23.

### 4.9. Hook bounce.

The bounce behaviour of an arrester hook making contact with the deck has an important bearing on ensuring its engagement with an arrester wire. With heavier installations and higher speeds, the problems are now much more important. The hook has been allowed to drop under gravity but examination of the conditions to-day shows that some additional force is necessary to reduce the natural period of bounce.

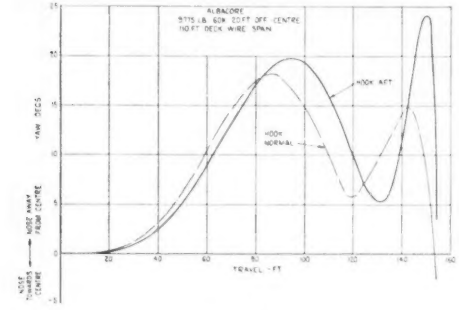



Fig. 23.
Yawing displacement of Albacore during arresting off-centre.

Bounce is initiated by the impact on the deck caused by the vertical velocity of descent or by projections on the deck, such as rivet heads, ropes and rope suports and in the case of a low approach, hook impact on the round down.

The necessity for a holding-down torque equal in effect to that due to constant value of at least four times the gravity moment (hook horizontal), plus a torque to balance slipstream effects on a faired hook, is considered essential.

### 4.10 Hook design.

The arrester hook by virtue of its position on the aircraft, if for no other reason, is required to be the minimum possible weight consistent with strength and wear.

A great deal can be said on the theory of the hook design and by careful tests and study of the hooks under load, an efficient construction has been produced. Two factors are important. The first is the radius of the hook coplanar with the rope and the second the rope-hook relationship in wear.

A wide range of experiments have been made and extensive tests, using many kinds of materials, have led to the present designs of the forged and welded-plate types. In the former, a forging technique had to be established.

The main factor governing wear was found to be the hardness of the throat relative to the wire hardness and the best results were obtained when they were equal. This hardness is now provided by a proprietary material, " Colmonoy," which is deposited by flame on the throat of the hook and dressed up to correct shape. The depth of the deposit is about .030 in.

In the snap gear type of hook, trouble was experienced because the slots in the throat, for the ejector lever, reduced the bearing area and it was necessary to design the new hooks

so that there was no interruption in the rope bearing surface.

In general, the welded type of hook is the better one—it appears to have local resiliance at the throat which prevents the high spots from scoring under intensive pressure. The solid forged type is less satisfactory in this respect, but is still a considerable advance in the reduction of rope and hook wear.

The table of weights of arrester hooks in use is given in Fig. 24 against the ultimate load. Fig. 25 shows the forged hook and Fig. 26 is a view of a plate-type arrester hook.

## 5. SAFETY BARRIER.

### 5.1. INTRODUCTION.

Crash barriers, as they were first called, were introduced into the Royal Navy in 1938. The first design was tested at Farnborough and considerably modified before installation in H.M.S. *Ark Royal*. The first equipment followed very much in principle the early ideas on arrester gears and two independent hydraulic units were directly connected to the ends of the barrier net. The layout of barrier equipment today is generally similar to the arrester gear and one energy-destroying unit deals with two barriers. The deck arrangements have changed in detail only.

The barrier is essentially an emergency arrester gear designed to prevent the aircraft over-shooting into the forward park and to protect personnel from injury.

Barriers were in use in the American carriers before 1938 and they differ materially in the deck equipment from the British type.

| Type. | Installation. | Alternate load, lb. | Weight lb. ozs. |
|---|---|---|---|
| Welded-Plate | S | 32,000 | 3 — 8 |
| | | 48,000 | 6 — 2 |
| | | 64,000 | 7 — 12 |
| | | 80,000 | 9 — 8 |
| | V | 24,000 | 4 — 0 |
| | | (Side load = 1,500) | |
| | | 48,000 | 7 — 12 |
| | | (Side load = 3,000) | |
| | | 60,000 | 9 — 8 |
| | | (Side load = 3,750) | |
| Forged | S | 32,000 | 3 — 8 |
| | | 48,000 | 4 — 0 |
| | | 64,000 | 6 — 8 |
| | | 80,000 | 8 — 8 |
| | V | 74,000 | 8 — 0 |
| | | (Side load = 9,250) | |
| Original Hook H.T.S. Side Plates | V | 48,000 | 7 — 12 |
| | | (No side load) | |
| | | 22,500 | |
| | | (Side load = 2,800) | |

S = Sting type. V = V-Frame type.

Fig. 24.
Table of hook weights and ultimate loads

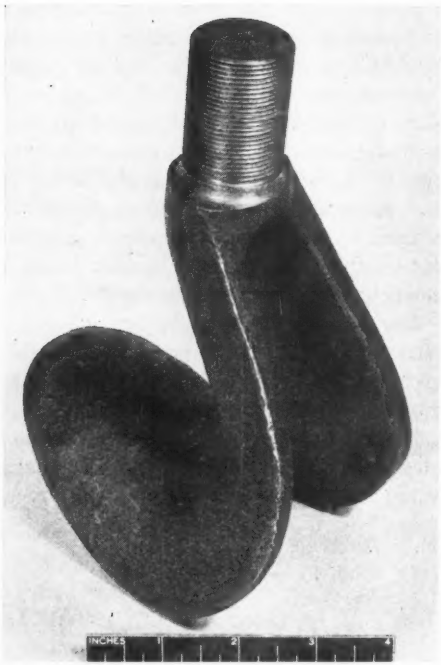



Fig. 25.
Forged steel hook

5.2. BARRIER OPERATION AND REQUIREMENTS.

The barrier divides the flight deck into two parts and is designed to arrest an aircraft which has failed to engage the arrester wires. Without a barrier, aircraft on the deck must be struck down before the oncoming aircraft can be accepted.

The operation of the barrier in the normal landing cycle is as follows:—

(a) aircraft lands on—barrier up.
(b) barriers down immediately aircraft engages an arrester wire.
(c) aircraft arrested, released and moves forward to the forward park or to be struck down.
(d) barriers up, aircraft signalled on.
(e) aircraft lands on, and so on.

This cycle must be as rapid as the aircraft can be landed on. Aircraft picking up late wires may, in the later stage of the arrester run, engage a barrier and avoidance of this depends entirely upon the alertness of the barrier worker.

Barriers are designed to receive aircraft at entry speeds up to 40 knots with a pull-out of 40 ft. and a mean acceleration of 1.9g., the 40 knots being based on the loss of speed of the aircraft from touch-down to barrier. Present-day equipment in American carriers caters for entry speeds up to 60 knots, but much longer pay-out, up to 100 ft.

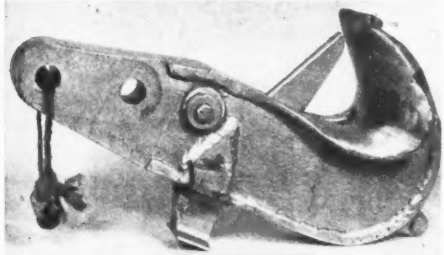


Fig. 26.
Welded plate hook

5.3. BARRIER NET—DECK EQUIPMENT.

Both British and American forms of net were used during the recent war.

The British barrier consists of two main ropes spanning the deck and spaced 3 ft. apart, one above the other, by spreaders at each end. Vertical ropes are laced between the two main ropes to form a very open net. The spreaders are connected to a double reeved wire rope through an anti-friction swivel and a load equalising link (Fig. 27), which is intended to maintain equal tensions in the two ropes of the main reeving. The two ropes pass through a trumpet guide at the top of each stanchion and thence over guide pulleys to the hydraulic unit. Rope loads are thus taken on the stanchion structure, which must be rigid. The spreaders (and

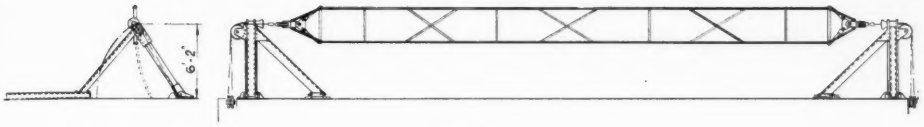



Fig 27.
Diagram of barrier net and stanchion.

therefore the net) are held in the vertical plane by a breaking link attached to the deck.

The stanchions are in the form of a tripod, which can be varied in height. The maximum height of the net at the centre of the deck is 7 ft.

In the standard arrangement of American barrier, the ropes render from deck level. The top rope is held 4 ft. and the lower rope 3 ft. above the deck by light removable struts. There is no lacing between the wires. The ropes are held tensioned by a light winch rope rendering from a hinged bracket. This light rope is disengaged through a shear pin when the barrier is pulled out.

### 5.4. Under-deck equipment.

The installation and equipment follow the general lines of an arrester gear, except that the hydraulic unit has a shorter stroke and is double rove on a 4:1 system. No control value is provided and the gear is not set to suit the weight of aircraft.

The American unit is a standard arrester gear, but reeved 6:1 instead of 10:1.

### 5.5 Barrier engagement.

Although the primary object of the barrier is to prevent injury to flight deck personnel and aircraft crew, it must also cause as little damage to the airframe as possible and in such a manner that it can be wheeled away immediately and the deck cleared for the next landing.

The problem is not easy. The British net is designed to take the aircraft around the engine, or the underside of the engine nacelle. In general, the propeller weaves through the net, although occasionally it does pick up a wire and cut it. If the aircraft is engaged in this way, it is generally arrested successfully but the damage may be heavy, especially as entry speeds are now generally higher than those for which provision was made originally.

Rendering the net parallel to the deck from the top of the stanchions tends to reduce the pitching, but invariably the net slips below the engine nacelle and a pitching moment, which throws the aircraft up on to its nose, may develop, especially if the airframe, particularly the undercarriage, does not collapse. In fast entries with float, the aircraft may be thrown completely over the net on to its back. Equally dangerous to the pilot and the crew is the top rope riding over the engine and crashing through the cockpit with risk of decapitating the pilot.

In the American method, the aim is to engage the aircraft at the undercarriage and strength requirements are specified to take these loads, which are less severe than those experienced with the British method.

No nose-wheel aircraft is yet in service on the deck, but it is possible that the barrier engagement will be more controllable and predictable. If the barrier is designed to engage the main undercarriage, the nose wheel will provide a stabilising force to prevent pitching and with the C.G. forward of the pick-up points, the engagement will be stable in yaw. This pre-supposes that the operational requirements on the deck can allow a longer pay out on the barrier to reduce the retarding forces.

The British barrier has a considerable advantage over its American counterpart, in that the resistance is offered immediately on engagement. The American barrier develops

slack and high impact forces must occur when this is taken up.

5.6. PHYSIOLOGICAL ASPECTS.

Little quantitative, or qualitative, information is available on the actual performance of the safety barrier, but retardations up to 10g. have been recorded.

Physiological aspects are generally covered by crash requirements, except the small possibility of injury caused by a rope being thrown over the top on to the cockpit. The greatest risk may come from fire.

CONCLUSION.

As I stated in my introductory remarks, I have not talked at any length on the engineering aspects of the equipment. Each section, if dealt with in this way, would be worthy of its own paper. I have attempted to present a related story on the general problems associated with equipment in use in the Royal Navy to-day. The future will intensify these problems.

It is my personal opinion that the operation of aircraft from carrier decks can be turned into an advantage over land-based aircraft. Before this can be done catapulting must be the normal means of take-off, methods for dealing with higher approach speeds must be found and new techniques must be adopted for the higher performance aircraft now with us and promised for the future.

My thanks are due to the Ministry of Supply and the Admiralty for permission to read this paper and to my colleagues at the R.A.E. for their ready assistance in its preparation.

REFERENCE.

1. Proceedings of the R.Ae.S. Fifth Meeting, 67th Session, 25 February 1932.
"Catapults and Catapulting of Aeroplanes"—Mr. P. Salmon, M.I.M.E., M.I.A.E.

## DISCUSSION

**The Chairman:** As Mr. Boddington's paper was, to some extent, supplementary to Mr. Farren's paper, reference to both papers would not be out of order.

**Mr. J. L. Bartlett** (Naval Construction Dept., Admiralty): The early winch gear for carriers, on which experiments were made at Farnborough, might have been far more successful had it not been circumscribed by the restrictions imposed by the aircraft. The early aircraft were far too sensitive to deceleration forces. With modern aircraft the characteristics of the winch gear were not so objectionable; in fact the most modern hydraulic gear had many characteristics that were similar to those of the original winch gear.

It was practically certain that velocity had a small physiological effect and deceleration and acceleration were far more important. But it was extremely probable that the most important physiological effect was the rate of change of acceleration. He understood that designers of very high speed lifts worked to a figure of 7.5 ft. per second cubed for the rate of change of acceleration. But there the person was standing upright and the actual acceleration of g was never exceeded. The conditions in aircraft were entirely different, but it was probable that the rate of change of deceleration might be the most important factor.

Mr. Boddington had deliberately, he thought, confined his remarks to the existing arresting gear. The Director of Naval Construction had referred to some later developments of arresting gear and Mr. Boddington, who was familiar with all those later developments, would agree that they had made considerable advances. He would suggest that arresting gear could be designed with a speed of entry which was beyond the ability of the pilot. There must be a speed limit beyond which the pilot could not ensure touching down in the landing area.

Arresting gear for very high speeds of entry

was not amenable to accurate calculation. There were too many unknown factors, such as the shock wave in the wire, inertia, elasticity and so on. Because of those factors they could not proceed too confidently on the basis of calculation without experimental investigation. For many years the Director of Naval Construction had emphasised the need for such experimental arresting gear to be installed ashore, but it was only in recent years that they had managed to get such gear installed at Farnborough. When they had, from these experiments, complete performance data, they would be able not only to determine the capacity of existing equipment, but would be able to use that data to improve future designs and determine the ultimate limitations of arresting gear. It was only by closest collaboration between the design section of the Department of the Director of Naval Construction and the experimental section at Farnborough, that the perfect design would be achieved.

In the discussion following Mr. Farren's paper Mr. Davenport had suggested that there was a terrific handicap in limiting the folded width of the aircraft to 18 ft. He would like to point out that it was for that very reason that they removed that limit over five years ago. There was no reason why a limit of 18 ft. should have been set.

**Mr. S. Scott Hall** (Ministry of Supply, *Fellow*): He had been impressed by Admiral Slattery's emphasis on the point of starting with a good aeroplane. He did not think anybody could challenge that and everyone hoped that soon they would see Naval aeroplanes which would take their place in any such list as quoted by the Admiral. He inferred, if he had understood him aright, that the reason why they could not at the present time include Naval aeroplanes was because the Admiralty always required the best of everything in the way of equipment and demanded a wide range of armament. The reason probably lay rather with the essential limitations imposed by the operation of those aircraft from carriers. It would be extremely interesting if aircraft designers could bring out in the discussion whether they felt that it was because of the complexity and variety of equipment, or whether they really thought Sir Charles Lillicrap's meeting was overdue.

The development of armament under war conditions had been singularly rapid and, in fact, had outgrown the original uses to which it was intended in that direction to put an aeroplane. He thought it was because in the past, little thought had been given to armament and those who had turned their attention to it in time of war had found an easy field in which to make rapid developments. That had made the task of the aircraft designer singularly difficult. He wondered if that situation would ever arise again.

There had been a change in outlook now on the question of armament. They were not going to allow armament design to lag behind in time of peace and the whole trend of design was getting so complex that they could not afford to do so. They were getting to the position where the armament in an aeroplane was a complex piece of equipment, requiring a long development time and it had to be considered as part of the aeroplane from the outset. But he did not disagree with Mr. Farren's important point that an aeroplane must be designed so that it could be flexible.

**Captain (E) M. Luby,** R.N. (D.E.R.D., Ministry of Supply, *Fellow*): Mr. Farren had said that most aircraft would profit by an improvement in the economy of their power plants—he agreed—and that this would necessitate the development of power units specifically for Naval aircraft.

This suggested that such had not been the case in the past. From about 1938 onwards, a number of piston engines were developed almost exclusively for Naval aircraft, although some were later used by the R.A.F. They included the Perseus for Roc and Skua, the Taurus for Albacore, the Centaurus for Firebrand, Sea Fury and Spearfish, the

Griffon for Firefly and Seafire, the Eagle for Wyvern and special Merlins for Barracuda, and the new Supermarine Amphibian. In the pure jet field Naval aircraft were, for the time being, having to rely on those engines which had been developed for high-speed short-range R.A.F. aircraft; in the propeller turbine field at least 60 per cent. of the engines now under development were specifically for Naval aircraft—and they embodied a variety of complications in the coupling and declutching of engines in flight in order to achieve the maximum economy out of the peculiar basic characteristics of the gas turbine. These special mechanical devices were heavy and might introduce factors of unreliability—but they did help to meet the endurance requirements.

In his opinion the main requirements to be met by engines of Naval aircraft were as follows and in the following order of priority:

(a) reliability
(b) economy
(c) power
(d) weight

Unfortunately, his experience had been that some Naval aircraft designers generally chose an engine for their project in the reverse order.

It was uncanny with what regularity some designers under-engined their projects and then, at the last moment, expected another 200-300 h.p. to get the aircraft off the ground. It was to the credit of the engine firms that, to date, this last-minute demand had been met.

He would warn, however, that it would be unwise to count on this life-saver in the field of propeller-turbines.

To improve economy of turbine engines they could resort either to heat exchangers or could increase the compression ratio—both, unfortunately, would result in increases of weight—despite this, however, their new jet engines were being designed to specifications which called for much greater economy than was the case to-day.

What was required was the performance of a race-horse with the endurance of a cart-horse and this highly desirable result might possibly be achieved by careful selection and breeding, but this took a long time. It might be quicker to try and make it easier to drag the cart.

He agreed with Admiral Slattery's views on designing for maintenance. So long as maintenance of engines was necessary it must be capable of being done with ease and the minimum removal of cowlings—and this must be taken care of in the initial designs—but in the field of turbines he hoped that maintenance would be negligible. R.A.F. statistics showed that it was already four-fifths less than that required for the conventional piston engine.

**Mr. W. G. A. Perring** (Director, Royal Aircraft Establishment, *Fellow*): Sir Charles Lillicrap had endeavoured to show how flexible the carrier could be in its acceptance of a wide range of aircraft and had gone a long way towards accepting Mr. Farren's suggestion that they should make greater use of the mechanical advantages that formed part of any operation from a ship. The two lines on which these developments could take place were in take-off and landing, discussed by Mr. Boddington, and he would like to challenge Mr. Boddington to say what were the ultimate possibilities of doing more.

Mr. Farren had, he thought, rather brought home to them the fact that there might be serious limitations to arrester gear. It might not be possible to overcome the general elastic and inertia problems introduced by the weight and the complexity of the gear and the higher speeds and weights of aircraft to be handled by the gear. If that was so, they would be forced back again to develop high lift; in fact, with swept-back wings and the strange new plan forms, they were having to start all over again general studies on stability and control, methods of obtaining high lift and problems of lateral control at low speeds—matters that were engaging their attention

on conventional aircraft more than 20 or 30 years ago. The new forms of high-speed aircraft provided two particularly difficult problems in this connection; one, the general problem of being able to provide sufficient trim forces to take advantage of the maximum lift available and the other, the provision of adequate lateral control near the stall. Mr. Farren's curves challenged designers to achieve $C_L$'s of at least 2.8, a value that could only be achieved with some difficulty on aircraft of conventional design.

It was generally agreed that there was much to be gained by getting rid of undercarriages; there was a gain in speed, increased stowage space, greater wing stiffness and the chance of a greatly reduced structure weight. With the removal of the undercarriage there would, presumably, have to be general acceptance of a higher entry speed into the wire, so that once again it was important to establish the possible limitation of the arrester gear.

He saw no reason why any equipment carried on the ship could not equally well be reproduced on shore.

**Mr. C. C. Mitchell** (*Assoc. Fellow*): There was no doubt they could go a great deal farther than they had with catapulting, and to a lesser extent with arresting, and it was certainly within their power to achieve much higher performance in catapulting than had been required in the past.

The problem, as far as the engineer was concerned, was set by aircraft considerations and he thought in the past they had done for the aircraft all that they had been asked to do. To a large extent conditions which had had to be met in the giving of such services to the aircraft as launching it, had imposed a difficult problem. This applied particularly to the conditions in which an aircraft had to be carried, and to the manner in which the accelerating loads had to be applied to the airframe. In the past it had been necessary to apply the accelerating loads at certain points of the fuselage. The application of those forces at specific points on an aircraft had necessitated the use of what were relatively extremely heavy moving parts in the catapult and the energy of the catapult was largely absorbed by those heavy moving parts. The total energy generated by the power mechanism was that required to accelerate the aircraft and the moving parts of the catapult to the launching speed. When the aircraft left the catapult at the beginning of retardation the energy which had been given to the moving parts of the catapult was completely lost, so that assuming that the equivalent weights were equal to the weight of the aircraft the efficiency could not be more than 50 per cent., apart from frictional and other mechanical losses.

In the old days when they had to provide heavy cradles in order to carry the aircraft and apply the forces referred to, moving parts of the catapult became very heavy indeed and presented a tremendously difficult problem from the engineering point of view, in both acceleration and retardation. He hoped that in future they would be able to cut down those moving parts by simplification of the "mating" of the aircraft with the catapult. A great deal depended on that and the speeds which they should be able to attain with all the power available in a ship would be increased by such simplification. Simplicity of attachment of the aircraft was of vital importance as it not only cut down the energy wasted in every launch, but also affected the rapidity of operation and on these grounds must be given careful thought.

**Commander E. C. Beard** (R.A.E.): One point about the design of Naval aircraft which had not been sufficiently stressed was the ease with which the aircraft could be handled in restricted spaces on board ship. That was not confined only to free take-off, but more especially when the aircraft had to be catapulted. By the accepted methods for catapulting, the aircraft must be positioned accurately on the flight deck—within a matter of six inches in the athwartship direction—

and that could only be achieved in the time available for that positioning if due consideration was paid to it in the early stages of design. Normally speaking, for a free take-off the pilot could be waved off as soon as the previous aircraft had gone. For catapulting the pilot could not start to get into position until the previous aircraft had left. They were trying to get down to very rapid rate of launching from carriers and it meant, in effect, that they were limited to something under ten seconds to position the aircraft. That could only be achieved if regard was paid to it in the very early stages of design.

They had been striving for a long time to use all the power which was available in the carrier for launching the aircraft. Mr. Boddington had touched slightly upon this when he referred to the proportion of power which they were using at the moment. In the latest carrier it was a considerable proportion for the short time during which the aircraft was launched and in the new proposals it was an even greater proportion.

Would Mr. Farren illustrate what he had in mind?

**Flight Lieut. Evans** (R.A.F., Cranfield): What research had been conducted into the use of reversible pitch airscrews to supplement arrester gear?

**Mr. J. H. Meacock**: He would like to know something of the vertical loading imposed on the deck during landing, duration and nature and how it would vary with increased landing speed.

**Captain Fancourt** (D.C.N.R.): In years gone by the question of the view of the pilot was carefully looked after in the design stages and they had aircraft which landed-on very slowly. The pilot was sitting up and had a good view of everything. Then followed in the Fleet Air Arm a period to which Admiral Slattery had referred, when they used aircraft that were designed primarily for other purposes and so the view of the pilot had become less and less. He thought he was right in saying that in the last war the view of the pilot was exceptionally bad, which made the crash rate high and upset flight deck operations. He thought the designers, who interested themselves now in the projects about which the Navy was thinking, fully appreciated that important point and the Admiralty were studying sketch designs which showed that this was realised.

On the other hand, designers were now asking, because of the good view, whether they could increase considerably the approach and landing speeds. The Navy was asked to consider landing-on with the aircraft coming in at 105 knots. In the days to which he had referred the landing speed was 55 knots—it was rather a large difference in speed and he thought it showed that they had made considerable progress. They must remember that in so many calculations the approach speeds and the like were based on normal conditions, and normal conditions were not always applicable to Naval operations; moreover, they had to consider getting aircraft back in the dusk or at night.

He would warn anyone who was thinking on the above lines that they were getting not far from saturation point. He agreed with Mr. Farren's remark that methods of increasing lift and such devices would want watching, otherwise they would get completely out of hand. Later he would like to hear further from Mr. Farren. He could give him some most interesting facts on the matter and perhaps, give a promise of something to come in the future.

**Dr. H. Roxbee Cox** (Chairman): He was interested to hear of the limitations imposed on the arrester gear from the stresses in the actual cables. It would seem that there must be two periods that could be defined in this way—first the period in which the transverse wave was reaching the first support, a period in which the stresses were defined by the speed of the aeroplane and the width between the supports; and secondly, the period in

which the stresses were presumably defined by the direct force applied by the aeroplane and the inertia of the system. In which period did the stress limitation appear? Was the gear likely to suffer from high stresses in the first or the second?

There must be a great similarity between the theory for the first period and that developed just before the war for aeroplanes flying into balloon cables. In case Mr. Boddington did not know of that work he mentioned it and suggested that possibly some of his problems of wave transmission in cables had already been solved in a convenient way. A great deal of information existed of a theoretical and practical nature.

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**Afternoon Session—In the Chair, Sir John Buchanan, F.R.Ae.S.**

# OPERATIONAL FLYING

*by*

**COMMANDER F. M. A. TORRENS-SPENCE, D.S.O., D.S.C., A.F.C., R.N.**

*Commander Torrens-Spence entered the Royal Naval College, Dartmouth, in* 1927 *and after serving at sea with the Home Fleet and on the East Indies Station began Flying Training at No.* 1 *F.T.S., Leuchars, in* 1936. *He served then with H.M.S. "Furious" and later with H.M.S. "Glorious," Mediterranean Fleet. After the outbreak of the war he joined No.* 819 *T.S.R. Squadron and served on H.M.S. "Illustrious" from May* 1940 *until she was bombed in January* 1941, *during which time he was awarded the D.S.C. for his part in the raid on Taranto. He subsequently commanded No.* 815 *T.S.R. Squadron in the Western Desert, Crete, Greece and Cyprus, and then returned to England to serve with the Aeroplane and Armament Experimental Establishment, Boscombe Down, until May* 1945, *when he was appointed Commander (Flying) in H.M.S. "Illustrious." Since March* 1947 *he has been O.C. Flying, Empire Test Pilots' School.*

## INTRODUCTION.

THE title "Operational Flying" gives considerable latitude, although a title such as "Naval Air Operations" would be more descriptive. I propose to spend rather less than half my time talking about operations with which I was personally connected. One reason for this is that my experience of first-line flying did not extend beyond the end of 1941 and therefore can hardly be considered to be of topical interest.

After that I will say something on the subject of Naval air operations as a whole. I will also touch on such points as ship-based flying from the pilot's point of view; the way in which the carrier is fitted in as part of the fleet; the relative merits of ship- and shore-based aircraft in different circumstances; the so-called vulnerability of the carrier; and finally, a brief outline of the current types of aircraft in service and of the capacity of a typical carrier from which they would operate.

Any opinions expressed are my own. I do not propose to go into any of the revolutionary changes which we may expect in the atomic warfare of the future. This subject could only be dealt with in a separate lecture which I would not be qualified to give.

## NAVAL AIR OPERATIONS 1940-1941 IN THE MEDITERRANEAN.

In the summer of 1940, the Navy had five aircraft carriers afloat: the new *Ark Royal;* the *Furious* and the *Eagle*, whose hulls dated from the 1914 War; the old *Argus*, which had started life as an Italian liner; and the *Hermes*, a small but much newer ship. Before the introduction of air warning radar no means had been evolved for intercepting enemy air attacks on ships at sea. Sound locators did not work at sea because of the machinery noises in ships. Exercises had been tried, with little success, in which destroyers were distributed round the Fleet at a range of fifteen miles or so in the hope that they would see incoming aircraft. Otherwise, the only thing to do was to maintain uneconomical fighter patrols which were expected to detect as well as intercept enemy aircraft. In these circumstances fighters were of doubtful utility for defensive purposes and it is safe to say that by this method we could not have supported the war at sea against shore-based aircraft for any length of time after the fall of France. The old policy had therefore been to pack the carrier with torpedo-reconnaissance aircraft and to endeavour to hit the enemy before, and harder than, he hit you. This would have been of no avail against shore-based aviation.

In June 1940 the *Illustrious* embarked her squadrons for the first time and sailed for Bermuda for a working-up cruise. She was the first of the new class of armoured Fleet carriers and this was a significant moment in the development of ship-based flying. She embodied three important new features. These were an armoured flight deck, safety barriers and the installation of air warning radar. The value of the armoured deck was a matter of some controversy until very late in the war when it proved its worth against the Japanese suicide technique in the Far East.

The significance of the safety barrier, which was of American origin, lay in the fact that it enabled the landing-on of the aircraft to be done about four times as quickly as before, and also increased the aircraft capacity of the ship by some 40 per cent. Air warning radar was a British development and the introduction of this and the safety barrier, transformed the carrier into a really effective floating fighter base.

The introduction of radar was also the deciding factor in enabling single-seater fighters to be operated from ships from the navigational point of view. But it was not until late in 1941 that the Hurricane and Wildcat fighters were actually embarked in our carriers. In fact, the potentialities of the carrier were not exploited by us in the early years of the war because of the lack of suitable hooked fighters.

The *Illustrious* completed her working-up in August 1940. Our precarious situation at the time needs no emphasis, our military forces in the Middle East being apparently isolated by the fall of France and Italy's entry into the war. The ship carried 18 Fulmars of 806 Squadron, which was as many as had been produced at that time, and 21 Swordfish of 815 and 819 Squadrons.

It is interesting to recall an interception exercise that was carried out on passage to Gibraltar, when the Fulmars intercepted a mock attack by the Swordfish squadron at a range of 40 miles. I think this was the first occasion on which any aircraft carrier directed its own fighters to an interception and the technique was now to be put to the test of battle also for the first time.

The object of the operation was to run through the Mediterranean, in company with the *Valiant* and some cruisers and destroyers, and thus to reinforce the Mediterranean Fleet at Alexandria under Admiral Cunningham. The movement was also required to cover the passage of a convoy. It was to be an operation of great significance for the future. In effect, the test was whether a Naval force could pass through a thousand miles of narrow water dominated by enemy shore-

based aircraft. In this connection it should be remembered that the Italian Air Force was largely designed for the very purpose of denying the use of the Mediterranean to enemy shipping, that they also had a large submarine force and a considerable Battle Fleet. It transpired, however, that their policy with regard to the last was to conserve them until the completion of two new 35,000 ton ships, so that our initial operations were opposed only by submarines and aircraft.

In the light of the knowledge and experience available at the time, this was a daring enterprise and at the same time, the acid test of our ability to pursue the war with any hope of success. The force was accompanied as far as Sardinia by Force H from Gibraltar, which included the *Ark Royal*.

She had no radar and her fighters were Skuas. A number of enemy reconnaissance aircraft were shot down by our fighters during the run in, but the enemy succeeded in launching a number of level bombing attacks in the vicinity of Sicily and Malta. These did no damage in face of our fighter opposition and all ships arrived at Alexandria unscathed.

The success of this operation proved greater than anybody had dared to hope. But the real point was that it opened up the possibility of our establishing a secure grip on the Mediterranean sea route. If this could be done, the liquidation of the Italians' African Army would follow and thereafter we could confine the war to the continent of Europe, holding the Mediterranean sea-board with our Naval and Air Forces only. It is amazing how near we got to achieving this by the end of 1940, when Wavell's offensive was well on the way to Benghasi. But the whole project really depended on our two carriers, one at Gibraltar and one at Alexandria and in particular, upon their two fighter squadrons. Every British warship or merchant ship that passed through the Mediterranean was dependent on those two squadrons to prevent their being sunk by the Italian Air Force.

During the next four months a remarkable supremacy in the Mediterranean was established over the Italians by the Royal Navy. Frequent convoys were passed through the Mediterranean, the practice being for Force H and the Mediterranean Fleet to put to sea together, the former in company with the convoy, which was then passed to the latter in the Sicilian narrows. This operation was performed about two or three times a month with the result that General Wavell was supplied with the necessary modern armaments in sufficient quantity to achieve his incredible offensive. During these operations, the Swordfish aircraft were used to keep down enemy submarines, in reconnaissance flights as a precaution against a sortie by the Italian Battle Fleet and also in bombing, torpedo and mining attacks on enemy bases.

Benghasi, Tripoli, the Dodecanese Islands and Taranto were subjected to these attacks by the Swordfish squadrons, the last being the most effective and best known. It is amusing now to recall that this remarkable operation was done with only 11 torpedo aircraft and 11 bombers and flare droppers. Furthermore, the attack on Taranto was really only the secondary objective of that particular operation, the primary objective being, as usual, the safe passage of a convoy to Egypt. The measure of the helplessness of the Italians in dealing with our carriers was the feebleness of their retaliation on the day after the attack on Taranto. Although the Fleet was little more than 200 miles from Italian territory next morning, the only attack by the Italian Air Force which penetrated within sight of our Fleet was forced to jettison its bombs.

The success of our Naval aviation at this period has sometimes been ascribed to the inferior equipment of the Italians. This assertion does not really bear examination. Our own aircraft were, if anything, less advanced than those of the Italians and numerically there was no comparison. The Fulmar had a poor climb and a bare margin

of speed over the S.79 bomber; neither can the Swordfish be described as modern equipment even in 1940. The difficulties of the Italians were, in fact, only those of any shore-based Air Force in dealing with a Naval Task Force incorporating an adequate air component. Attacking such a force is unlike other shore-based air operations because the position of the target is not known unless it is continually shadowed. If contact is lost for two hours the target might well have moved 50 miles by the time the attack can be delivered. Continuous shadowing by reconnaissance aircraft is a singularly difficult and dangerous proceeding in face of ship-based fighter opposition.

The result of this situation was heavy losses by the Italians of reconnaissance aircraft and complete failure to deliver an effective attack. To add to the discomfiture of the Italians, their Battle Fleet was now neutralised, although before the attack on Taranto it had been much stronger than ours. On the occasions when it put to sea it soon found itself in an area dominated by our fighters and therefore in the fatal position of any surface ships at sea with local command of the air held by the enemy.

After Taranto, British Naval control in the Mediterranean was firmly established. During November and December 1940, no enemy aircraft penetrated within sight of the *Illustrious* and our convoys moved freely. General Wavell's great offensive, supplied by our Mediterranean convoys, was well under way and the Greeks were encouraged to resist Italian aggression. It is often forgotten that at this time our position in the Mediterranean was held to be so strong that Mr. Churchill felt himself able to address a radio speech to the Italian people advising them that their only possible course of action would be to abandon the war.

As I have said, however, the whole edifice of our power against Italy depended upon two aircraft carriers and their fighter squadrons. We were now suffering anxiety because insufficient Naval fighters were being produced to keep these squadrons up to strength. Also, it was clear that the performance of the Fulmar would not be adequate for much longer and no replacement was in sight. By the new year 1941, the *Illustrious* was reduced to 12 Fulmars, many of them in a bad state. It may also be said that our firm ascendancy had given rise to some overconfidence. The reaction of the Germans to the catastrophic situation which had developed for them in the Mediterranean was to send their Stuka forces, fresh from their defeat by Fighter Command in the Battle of Britain, down to Sicily. Unlike Fighter Command, we had no resources to meet them. Our one depleted fighter squadron could hardly be expected to hold off the weight of both the Italian and German Air Forces in the Mediterranean.

This situation coincided with an ambitious convoy project. At dawn on 6th January 1941, the Mediterranean Fleet appeared within sight of Pantellaria to pick up another east-bound convoy. There was, therefore, no necessity for the enemy to shadow our forces.

There were, I think, only five serviceable fighters left on the *Illustrious* by noon on that day, out of the squadron of 12, although we had only lost about three by enemy action in four months. Two were on patrol and three in readiness on deck. Two S.79 torpedo aircraft penetrated to the Battle Fleet and the two fighters on patrol were called down to chase them. Soon afterwards a heavy Stuka attack was launched against the *Illustrious* and the two aircraft which had been brought down had not sufficient performance to get up again to meet them. The three aircraft on deck got off just as the first bomb struck. The attack was therefore quite unopposed and the ship suffered the inevitable consequences of the loss of local air superiority. Having dealt with the carrier, the remaining ships of the convoy were subjected to further heavy attacks which sank a cruiser. Fortunately, the *Illustrious* and the convoy got

into Malta, although the ship had sustained six bomb hits, mostly from thousand pounders and had 120 men killed and 120 wounded. The fighter squadron was virtually destroyed and the two Swordfish squadrons reduced to one.

The consequences of this disaster were immense and, to my mind, have not yet been fully recognised. Our communications through the Mediterranean were blocked; those of the Italians restored, except in so far as we could hamper them from Malta. The Mediterranean battleships were reduced to coastal operations within range of our existing shore fighter bases. It is true that the *Formidable* was sent out round the Cape, arriving in March and that she passed some further convoys. Incidentally, she also provided the essential air element which made possible the victory of Matapan. But during the evacuation of Crete she met the same fate as had befallen the *Illustrious*. In her case I think I am right in saying that she only had two serviceable fighters available when she was attacked by Stukas, with an escort of M.E.109s.

I have emphasised the weakness of our Naval aviation because I believe it to have been the primary cause of the precarious position in which we found ourselves in the Middle East in 1941 and up to the battle of Alamein in November 1942. It is true to say that our control of the Mediterranean and therefore of the military situation in the Middle East, broke down on the 6th January 1941, when the *Illustrious* was eliminated. Based on the experience of the Battle of Britain it is fair to say that six Hurricanes could have broken up the Stuka attack and preserved the control which had been so firmly established in August and December 1940. But for this reverse the ability of the Italians to pursue the war after the early months of 1941 would have been doubtful. As it was, we were forced from then on to endeavour to supply the Middle East via the Cape route. This route required six times the shipping tonnage required by the direct route to supply the same amount of material. As we had not the tonnage available, the reason for the long ding-dong campaign in the Western Desert is evident.

The prize which was practically within our grasp in January 1941 was not finally won until two years later and it took almost the whole of the military effort of the Empire to do it during that time. We had to supply a campaign in the Middle East round the Cape route for two years and finally, land another army in French North Africa. Both armies together then had to fight the hard road across the breadth of Africa to Tunis. Only then did we get final control of the Mediterranean and set about winning the war.

The next carrier operations in the Mediterranean were confined to supplying Malta from the west. Among others, the U.S. carrier *Wasp* was used for ferrying replacement aircraft to Malta. The next convoy operations were mounted in the autumn of 1942 with the limited object of getting supplies to Malta. The only carriers available at this time being the ancient *Eagle*, *Furious* and *Argus*.

The collapse of our military position in the Middle East in 1942 was not the only example of our dependence on sea communications for conducting operations overseas. To digress momentarily to another theatre of war, the military disaster of Singapore was also caused by our loss of command of the sea. The Japanese were thereby enabled to land sufficient military forces in the peninsula to capture Singapore. The holding of Singapore was bound to be conditional upon our retaining command of the sea in that area. As in the Mediterranean, we lost this command because of the deficiency of our Naval aviation, or in this case, the complete lack of it. Without the support of one or more carriers, the *Prince of Wales* and the *Repulse* were little more than a liability. Had we had a carrier force, the forces which the Japanese used to effect their landings could

have been frustrated. It is tantalising to consider the course the Far East war might then have taken.

In the Mediterranean my personal experiences after the bombing of the *Illustrious* were confined to shore-based operations. As there were no R.A.F. torpedo aircraft in the Mediterranean until late in 1941, when some Wellingtons were converted and some Beaufighters arrived, the Naval Swordfish were in some demand. The remains of the Fulmars of the *Illustrious* were absorbed into the defence of Malta and the Swordfish, after a short interlude in the Western Desert, were sent to Greece where considerable damage was done to the enemy communications in the Adriatic.

It became patently clear during that campaign that it was far easier to sink five or ten thousand men in a ship than it was to kill them with bombs or bullets once they had got dispersed and entrenched in mountain or desert. The same goes for ten thousand tons of ammunition.

The Swordfish squadron also took part in the Battle of Matapan off the coast of Crete. After the fall of Crete, again caused by lack of fighters, the squadron was divided between Cyprus and the Western Desert. The former detachment was used for the blockade of Syria during that campaign. It was a matter of some satisfaction to us, and another instance of the dependence of land campaigns on sea communications, that General Dentz, commanding the Vichy Forces in Syria, took pains to explain in his capitulation speech that he was unable to continue because of the lack of supplies and reinforcements.

To illustrate the general shortage of aircraft in the Middle East at that time, it is worth mentioning that the defences of Cyprus, when we arrived there, consisted of three Hurricanes. These had to be taken away a week later so that the Syrian campaign could be started. The biggest gun on the island was a Bren gun; there was no radar and no searchlights. At the time, Cyprus was logically the next objective of the Germans after the capture of Crete. It was indeed fortunate that they abandoned their drive in the Middle East to begin their attack on Russia, but they did not do so before we had been repeatedly frightened by reports of concentrations of troop-carrying aircraft in the Dodecanese.

The detachment of Swordfish and Albacores in the Western Desert was an invaluable aid to the Desert Air Force bombers. It was found that the remarkable visibility from their cockpits, and their manœuvrability and suitability for night flying, made them ideal for detecting and illuminating by flares, enemy targets in the desert. The effectiveness of the Desert Air Force night bombing was thereby increased out of all proportion to the small additional force represented by the Naval squadron. In fact, the origin of the Pathfinder technique has been traced to these operations.

I left the Middle East at the end of 1941 and for three and a half years from 1942 became engaged upon testing at A. and A.E.E., to return to the *Illustrious* as Commander (Flying) three months before the end of the Japanese war. The ship was doing a quick modernisation and refit at Rosyth with the hope of getting out to the Far East again before the end of the war. This was not to be and we took over the job of trials carrier at Portsmouth.

## TYPICAL OPERATIONS OF THE LAST WAR IN WHICH NAVAL AIRCRAFT FEATURED PROMINENTLY.

With one or two digressions I have dealt with operations with which I was personally connected, which really gives a very imperfect picture of the whole subject of Naval air operations. If you look at all the operational flying that was done at sea during the last war, it seems to me that you can divide it into four groups, or classes, of operations, each having different objects and characteristics. I propose to discuss each group in turn.

They are, first, the covering of our own shipping movements in the face of enemy action by shore-based aircraft, submarines or naval forces.

Second, the converse of the first, which is offensive action against enemy shipping at sea.

Third, the deliberate engagement of our ship-based aircraft with enemy shore-based aviation at short range to cover a military landing or evacuation.

Fourth, the "set-piece" raid against an enemy shore base or special target.

DEFENSIVE ACTION.

The first type of operation, the protection of our own or allied convoys is a defensive function and therefore it may not seem right to deal with it first. Nevertheless, I consider it to be the fundamental function of the Navy in war.

The old orthodox theory was that the best way to defend one's own ships was by offensive action against the enemy battle fleet. This was clearly quite right when the enemy's battle fleet was the only possible threat to one's own shipping. But nowadays shipping at sea is continuously exposed to submarine and shore-based air attack and, unless you can defeat these attacks, there is no reason why the enemy should go to the trouble of building a surface fleet. Nowadays, generally speaking, continental powers prefer to use submarines and aircraft for attack on the communications of a maritime power.

The counter-measures open to the ship-based aviation of the maritime power against these activities are essentially defensive. Admittedly, if the enemy has an effective surface fleet, it is still necessary to take the offensive against it with all the means in your power, but the defensive measures against the other forms of attack can never be relaxed. Thus all ships at sea must have continuous protection against all forms of attack which can be launched from enemy shore bases within range. This range is always tending to increase and it is therefore somewhat of a paradox that the greater the range and striking power of shore-based aircraft, the greater is the need of a maritime power for ship-based defensive fighters.

In the last war we did not achieve tolerable fighter defence for our convoys in the Atlantic or elsewhere until some time in 1943, which resulted in colossal losses of shipping with their priceless cargoes on which we lived and maintained the whole war effort. Yet during these first few years vast numbers of aircraft were being manufactured by us for uses which some people might now consider to have represented an uneconomical expenditure of force. During the early years of the war it frequently happened that a single German reconnaissance aircraft was able to shadow a convoy for hours, enabling a pack of submarines to be concentrated which then wrought great devastation. On these occasions only one fighter would have been required to destroy the reconnaissance aircraft and prevent the disaster. After such experiences as these, single fighters were mounted on catapults in merchant ships. After one shot, a pilot had to ditch or attempt to make for the nearest land. Even this crude and inefficient improvisation was a great success, which is a measure of the predicament in which we were placed.

In this connection it should be mentioned that it is not a fair criterion of Naval Aviation to compare the number of enemy aircraft shot down with our own losses. What matters is the ships that have been saved. For instance, you might see in some aviation statistics the apparently insignificant item of one enemy aircraft shot down or damaged. This looks trivial, but in reality the larger part of a convoy might well have been saved. In terms of military economy, this item might well have been equal to the winning of a big battle on land or to the successful delivery of a heavy bombing attack with hundreds of aircraft. It is to shipping statistics rather than air statistics that one should refer when

assessing the success or otherwise of Naval air operations.

Although Naval convoy operations are the least spectacular, they are fundamentally the bread and butter work of the Navy and of Naval Aviation. They probably absorbed the greater part of our effort during the last war. At large distances from enemy bases, as in the Atlantic, where enemy action is likely to be relatively weak because of the long range, the escort forces can be small. One escort carrier, two A/A cruisers and up to a dozen destroyers, escort vessels and corvettes, would provide good protection. However, in the case of getting a convoy through strongly held waters, such as the Mediterranean, it was found necessary in the later stages of the war to employ a carrier squadron of up to four ships with battleships, cruisers and destroyers in proportion.

For close escort anti-submarine work the advantage of carrier-based aircraft as against shore-based aircraft is evident. Economy is obtained by the use of small and manœuvrable aircraft of short range. All flying hours are expended on the job and not on passage. If the armament is expended the aircraft can be re-armed and be on patrol again in 10 minutes instead of, perhaps, 12 hours. These arguments apply even more strongly in the case of fighter cover. When a defensive fighter is required, it is required extremely quickly, as anyone who has seen a fighter airfield functioning will easily appreciate. It is therefore essential that the fighter base should be immediately at the scene of operations.

It is revealing to consider the case of a convoy moving through narrow waters, such as the Mediterranean, in the face of enemy air action for say, 1,000 miles of the journey. For instance, if it is required to maintain six aircraft on patrol and twelve at two minutes' notice, this can be done easily for prolonged periods by one carrier with, say, 36 fighters. To produce the same degree of cover from shore-based aircraft at an average distance of 100 miles, 18 aircraft would be required over the convoy continuously, with another 18 either coming or going. Furthermore, bases capable of mounting this effort would be required at intervals of every 100 miles. Some quick mental arithmetic will show the enormous difference in economy between the two methods of providing comparable cover.

There is another aspect to this. The fighter pilot from a carrier has an intense personal interest in the successful protection of the ships under his charge. He is, in fact, endeavouring to prevent his own home and messmates and personal property from being sent to the bottom. To the shore-based pilot the ships in convoy many miles out to sea present a somewhat less attractive proposition. It is not surprising that convoy covering work is not popular with the pilots put on to the work from shore bases.

### Offensive action.

The second type of operation is the offensive against enemy shipping. The objective of our Naval forces is not only to ensure the safe passage of our own shipping but also to deny the use of sea communications to the enemy. The ultimate objective is thus the destruction of all enemy merchant ships that put to sea. Traditionally, this could be achieved once the enemy's battle fleet was destroyed because no other form of protection existed for merchant shipping at sea. The whole Naval war strategy was therefore embodied in the idea of offensive action against the enemy's battle fleet. Nowadays, the variety of surface, under-water and over-water weapons has greatly complicated the problem. Nevertheless, it is generally agreed that the modern equivalent of the destruction of the enemy's battle fleet is the destruction of his carrier force if he has one.

The British Navy has not yet been engaged with an enemy possessing a carrier force. The Germans and Italians had no carriers, which was perhaps their biggest omission in their preparations for the last war. By the time

the British Navy was free for operations in the Far East, the U.S. Navy had already destroyed the Japanese carrier force. Apart from the Far East Naval war, we were engaged primarily with land power depending almost entirely on continental communications. There was little scope for attack on enemy ships, except for the counter-offensive against their submarines and the attack on their sea route between Italy and North Africa. In this last case we were fortunate in having an unsinkable aircraft carrier in the shape of Malta right in the middle of the route. Ship-based aircraft were therefore not greatly involved. In practice, our attacks against enemy shipping were largely opportunist. There were however a considerable number of instances of our ship-based aviation attacking enemy shipping with success at sea. Perhaps the best known instance was the destruction of the *Bismark*.

PROTECTIVE COVERING.

Thirdly, there is the deliberate engagement of ship-based aviation at short range to cover a military landing or evacuation. The orthodox doctrine, accepted before and during the early part of the last war, was that this type of operation was not practicable owing to the inferiority of Naval aircraft and to the vulnerability of the carriers. Nevertheless, as it turned out, all these operations were successful so the orthodox doctrine was demonstrated to be wrong. The explanation for this lies in the fact that the carrier aircraft had the advantage of mobility and therefore of initiative, concentration and strategic surprise.

Our first effort in this direction, neglecting the Norwegian and Cretan evacuations, for which we had negligible forces by any reckoning, was the Madagascan landing in 1942. The carriers used for this were the *Illustrious* and the *Indomitable*. This was followed by the successful landings in French North Africa at the end of the year. Then there were the landings at Salerno.

In this last case the Naval aircraft had assistance from shore-based fighters flying from Sicily. However, the R.A.F. Spitfires could only remain 20 minutes in the assault area, and the Lightnings one hour, because of the distance from their bases. For this operation we used the escort carriers *Battler, Stalker, Attacker, Hunter* and the *Unicorn*. It was intended that this support force should operate off the beaches for two days but because of delay in capturing the air-strip ashore, they had to keep it up for three and a half days. Seafires were in use in quantity by this time.

The last operation of this nature completed by us was the successful landing in the South of France in 1944, by which time the technique of air support for military landings was well developed.

It must be admitted that in all these operations, except Salerno, the opposition was weak. It is not often realised, however, that the American advance across the Pacific was achieved entirely by operations of this kind, in which the carrier force attacked and defeated in turn a succession of strong positions defended by shore-based aircraft. Their successive landings across the Pacific were entirely supported by Naval aircraft. After the initial landing and capture of the airfield, the shore-based aviation was able to move up to consolidate the position for the next advance. Before the end of the Pacific war the objective of the U.S. Navy had risen to nothing less than the destruction of the Japanese air power. This object had been achieved locally in each area selected by the Americans for the next advance. The final destruction of Japanese air power in the home islands was well under way when the atom bomb put an end to the proceedings. It should not be forgotten, however, that it was the advance of the U.S. Navy across the Pacific which secured a base sufficiently close to the Japanese home islands for the operation of the B.29s.

THE "SET-PIECE" ATTACK.

The fourth and last type of operation is the raid against an enemy shore base, usually referred to as a "set-piece." This is really rather similar to a Bomber Command operation at shorter range and with smaller aircraft. It can be worked out in detail before the fleet puts to sea and, of course, can only be done against a shore target.

The best known example of this type of operation on our side was the attack on Taranto but we did many others less well known and with varying degrees of success from Petzamo in Norway to Sabang in the East Indies. Sometimes, these attacks were the primary objective of the operation but more usually they were fitted in as a secondary consideration to the movement of a convoy, or to the passage of Naval forces from one theatre of war to another.

The most elaborate attack of this kind made during the war, was the Japanese attack on Pearl Harbour, designed to eliminate the American Navy at one blow. It was one of the most fortunate things of the war that the American carriers were not in Pearl Harbour at the time, which explains the quick recovery that the Americans made from this devastating blow.

## SHIP-BASED FLYING FROM THE PILOT'S POINT OF VIEW.

From the pilot's point of view it cannot be said that the differences between operational flying ashore and afloat are very great. The Naval pilot has the business of taking off and landing-on, by day and by night, perhaps with a pitching deck, all of which requires extra training and a specialised form of skill. Even on non-operational flights the landing-on provides some extra nervous stimulant that is not met with ashore. It is therefore urgent that Naval aircraft should be made as easy to deck-land as possible. Broadly speaking, the following characteristics are required:—

(1) Unimpeded forward view.

(2) Sufficient drag to ensure a steep gliding angle so that too much height will not cause a prolonged float over the wires. In the case of jet-propelled aircraft, a decent amount of drag also enables the turbine revolutions to be kept up during the approach so that the quicker control of thrust can be obtained. In this connection, the Vampire is now being tried with the throttle lever interconnected with the drag flap so that the drag is reduced as the thrust is increased and *vice versa.*

(3) The tricycle undercarriage is fundamentally right because it eliminates the bugbear of the deck-landing pilot, which is the bounce over the wires into the barrier. The snag is that it also encourages fast landings, thereby requiring heavier and stronger arrester gear, both in ships and aircraft. As yet, we have gained little experience with the technique required for deck-landing jet-propelled tricycle aircraft. It is also important that the landing gear should be capable of absorbing a high rate of descent without bounce or damage to the aircraft.

(4) Good lateral control at approach speed with flaps down. Corrections for line on the approach are done by aileron control but this feature becomes less important if there is a good forward view.

(5) Good warning of the stall, flaps down, power on.

(6) Good longitudinal stability to facilitate keeping a steady speed.

(7) Absence of directional and lateral changes of trim with power. This requirement can only really be met with contra-props or pure jet-propelled aircraft. Longitudinal change of trim with power flaps down should also be kept small.

For take-off, the principal requirements are forward view and absence of swing. I think that continual flying over the sea on one engine, with wartime maintenance standards,

puts more nervous strain on air crews than operational hazards. A great economy in air crew training and replacement would be effected by the use of twin-engined aircraft. Fortunately, this may be more easily achieved with turbine-jet engines than with reciprocating engines, and I hope to see twin-engined aircraft for all Naval types, except possibly short-range interceptors.

In connection with ditching hazards, it is interesting to note that the submarine was found in the last war to be a valuable instrument of air-sea rescue. Submarines stationed in anticipated areas of air combat effected many rescues, although this task was far from popular with submarine crews. The ditching properties of his aircraft are a matter of great concern to the Naval pilot. It is a considerable extra strain to know that you cannot go into the water in your aircraft without killing yourself.

## THE AIRCRAFT CARRIER AS A UNIT OF THE FLEET.

Although I have made it clear that I regard the aircraft carrier as the foundation of sea power under present conditions, there should be no illusion as to its dependence on other classes of ships. As I have said, in the old days, the battleship was self-sufficient and nothing could defeat it except a bigger and better battleship. Nowadays, no ship is self-sufficient in this way. No one type of ship can carry the variety of weapons which are required to prosecute the war at sea.

Nevertheless, the first requirement in maintaining local command of the sea is to obtain local command of the air. It is fair, therefore, to regard most other classes of ships as indispensable ancillaries to the aircraft carrier and to regard the Fleet primarily as a mobile floating air base. So long as you have local command of the air, you immunise yourself against attack by air weapons and secure an overwhelming advantage in dealing with surface ships and submarines.

At the present time it must be admitted that the carrier is not an all-weather weapon. When it comes to operating a carrier in a fog we are no better off than our shore-based colleagues at an aerodrome. In fact, when the aircraft are grounded, the carrier becomes a useless liability and the battleship is once again supreme. With the aid of radar, the effectiveness of the battleship is little affected by bad visibility. It is important, therefore, to push on as quickly as possible with means of deck landing aircraft in fog.

Again, if the carrier is to be laid out as an efficient floating airfield, its anti-aircraft gunnery arrangements must be somewhat restricted. The most ardent enthusiast of Naval Aviation would not deny that strong anti-aircraft gunnery defence is necessary to supplement the fighters. Even the most confident football team would not take the field without a goal keeper. The majority of anti-aircraft guns must, therefore, be distributed among cruisers and battleships and destroyers. As regards close cover against submarines, effective action can only be achieved by team work between aircraft and surface vessels.

The effective unit of sea power, therefore, instead of being a single battleship is now a collection of ships of different classes centred on the carrier. This unit is frequently referred to as a task force. If any one class of ship is deficient, the unit becomes vulnerable to some particular form of attack. The size of the task force can vary widely from one based on a single carrier to one based on four carriers. So far, four carriers have been found to be the biggest number which can be operated as a tactical unit. This is because of the congestion of air space resulting from the number of aircraft involved. If more than four carriers are employed, it is necessary to divide the fleet into two tactical units.

The modern formation of the fleet and task force is very different from that in vogue at the beginning of the last war. The carriers

are disposed in a square with a cruiser in the centre as guide of the fleet, upon which all ships keep station. The battleships and cruisers are disposed among the carriers in a regular formation and the whole is surrounded by a circular destroyer screen. The whole formation rather represents an anti-aircraft and anti-submarine hedgehog capable of being turned in any direction, all ships together, to suit the flying requirements of the carriers. It was found possible during the war in the Pacific to keep task forces of this type at sea in the battle area for six weeks continuously, by an elaborate system of supply of fuel, stores and ammunition at sea.

## THE VULNERABILITY OF THE AIRCRAFT CARRIER.

This was a subject about which much was heard before and during the war. What one might call the Seversky school of aviation strategists held that the carrier would be sunk by shore-based bombers. Similarly, those who believed in the big gun of the battleship, conceived the destruction which can be wrought by this weapon on the defenceless hull of the carrier. It is interesting, therefore, to recall the circumstances in which we lost our carriers during the war.

First, the *Courageous*, an old converted battle cruiser, was sunk by submarines which is likely to happen, and did indeed happen, to hundreds of ships of all classes which were not protected by both aircraft and a destroyer screen. The *Glorious*, of the same class, was sunk by enemy battleships but she was, in effect, being used only as a transport at the time. She was evacuating men and material, including an R.A.F. Hurricane squadron, from Norway and her operational aircraft consisted of only six Swordfish. She could not, therefore, be regarded as an operational carrier at the time. I have already mentioned the damage done to the *Illustrious* and the *Formidable* in the Mediterranean and have pointed out that these ships, to say the least, were not properly equipped with aircraft. The efficiency of these ships was no more tested by these actions than would the efficiency of a battleship have been tested by going into action with one turret instead of four. The *Hermes* was sunk by Japanese ship-based aircraft off Ceylon. She had no fighters aboard whatsoever. The *Ark Royal* was sunk in the Mediterranean and again, the submarine was responsible.

I think I am right in saying that all the escort carriers which we lost were sunk by submarines or mines and the exposure to these risks does not vary appreciably between different classes of ships, size for size. The deliberate engagement of our carriers with shore-based aircraft in the Far East for sustained periods resulted in only minor damage to our ships and we gave considerably better than we got. It is thus interesting to note that in spite of the millions of miles steamed by our carriers in waters open to enemy air attack, not one of our carriers was sunk by shore-based aircraft during the war.

## THE CAPACITY OF THE AIRCRAFT CARRIER.

A brief outline of the capacity of one carrier would not be out of place. In the Pacific, the *Illustrious* class were operating 50 aircraft, carrying 38 in the hangar and 12 on deck. The later fleet carriers were operating slightly more but the exact number depends primarily on the size of the aircraft. The normal frequency of take-off is about one aircraft per 15 seconds or, using a single catapult, one aircraft in 50 seconds. Thus for a "set-piece" operation of the type which I have mentioned, 50 aircraft could be got off each carrier in 20-25 minutes by combined catapulting and unassisted take-off.

The fleet carrier's deck is about 740 ft. long and 60-90 ft. wide. There are 10 arrester wires with a pull-out of up to 140 ft. The landing area is about half the total. The deceleration imposed on the aircraft depends on the speed of entry into the wires and 2g is a typical figure at the present time. The

landing-on interval is about 30 seconds. This is made possible by the safety barrier which is lowered as soon as each aircraft comes to rest. The aircraft, therefore, only has to taxi over the barrier to allow it to be raised so that the next aircraft can land-on. Each lift can only strike down aircraft at the rate of one every two minutes. Therefore, if you land-on 20 aircraft in 10 minutes you will fill up the deck park and have to wait until the aircraft are struck down before landing-on any more. The delay would be about 15 minutes using both the lifts.

Generally speaking, when operating the carrier the flow of aircraft within the ship is forward on the flight deck and aft through the hangar. Ranging-up is mostly done aft and striking down, forward. If you have less than, say, 12 aircraft in the air, the remains of the deck park must be shifted forward when landing-on and aft when taking-off. An elaborate internal organisation is required to control the movements, maintenance, arming and fuelling of this number of aircraft in the confined space. Power folding of wings is essential nowadays, since it effects an enormous saving in time and man-power.

## CURRENT TYPES OF NAVAL AIRCRAFT.

The current aircraft in service are the Seafire 15 series, single-stage Griffons, for defence and short-range escort and strikes. They are being replaced by the Sea Fury and the Seafire 47 series, the latter having two-stage Griffon engines with contra-propellers. Thereafter, it seems probable that the pure turbo-jet fighters will be used in this role.

The switch-over to jet propulsion will confer many advantages on Naval Aviation. Space being at a premium, the smaller size of jet-propelled fighters for equivalent performance is a great advantage at sea. The safer fuel reduces the hazards to the ship. Operational problems on deck will be eased by the elimination of the necessity for elaborate warming up of engines before aircraft can fly. Again, the saving in maintenance personnel on turbo-jet engines releases space in the ship for other purposes. Finally, the jet-propelled aircraft is ideally suited for the tricycle-type undercarriage, which is the pilot's ideal for deck landing.

The biggest problem to be faced is that of getting adequate endurance from aircraft without the use of propellers. Aircraft of short endurance impose a severe handicap on the tactical landing of the fleet. Also, there is much work to be done in evolving a new deck-landing technique.

## CONCLUSION.

In conclusion I would like to thank the Society for their gesture in inviting a serving Naval officer to contribute this paper.

Of the many people who are engaged directly or indirectly in the development and production of Naval air equipment, it is unfortunate that relatively few are in a position to keep in close touch with the Service. I have only been able to sketch a broad outline of some of the aspects of Naval air operations, but I hope it may have served to dispel any doubts they may have as to the value of their efforts to supply us with the material we need.

As regards the future, people have been heard to say that our position at sea will become indefensible in the face of atomic weapons and supersonic aircraft. If we allow it to become so, it means that we will be wasting our time in even trying to ensure the defence of the home country against these weapons. It is no use doing one without the other. More than any other major power we are militarily dependent upon the security of overseas communications. Whatever the future, the fact remains that we have to find the means of protecting our shipping at sea and it is to the development of the aircraft carrier and Naval Aviation to which we must look to achieve this end.

## DISCUSSION

**Admiral Slattery**: The lecturer had given them some good examples of where sea-borne air power had its advantages and had pointed out that there were occasions when it was a greater economy to operate from a carrier and indeed, on certain occasions a task could not be performed in any other way. He had always said in the course of Staff College lectures that no one but a fool operated an aircraft from a ship if it could be done more economically and equally efficiently from a shore base. Naval aviation was complementary to the Royal Air Force and in no way in competition with it. They had had two good examples in Commander Torrens-Spence's lecture of the importance of fighter cover in the Mediterranean and the fact that it had to be provided by aircraft carriers because they had lost control of the shore bases, from which, otherwise, it could in many cases have been provided by the Royal Air Force. It would be a greater economy of effort, particularly at long distances from shore bases, to operate aircraft for anti-submarine protection by carrier-borne aircraft; there was the advantage that they could be on the spot and thereby bring a concentration of force where it was wanted, with the minimum of delay.

From their experience in the Mediterranean it seemed that one of the things they must always have was carrier-borne fighter aircraft of the highest performance, comparable in every way to the aircraft which could be put up from the shore. Early in the discussion in the morning session they were led to expect, provided that they kept their heads screwed on right, that they could achieve that and it certainly was most important that they should.

The safety barrier increased the speed of operation in the carrier and incidentally enabled ships to stow a considerably larger number of aircraft on board. The potential of an aircraft carrier depended on the number of aircraft that could be operated in a given time; just as the potential hitting power of a battleship depended on the number of missiles which could be discharged at the enemy in a given time, and not by the number carried in the shell room, so it was with the aircraft carrier. It was quite clear that a larger number of small aircraft could be stowed in a carrier than large aircraft, and small aircraft could also be operated more quickly and easily. There seemed to be merit in smallness and the desire of the Fleet to keep their aircraft small, or to make them fit into small confines, was not just to pacify an inflexible and obstinate Director of Naval Construction, but simply because it was a good thing in itself. If they could keep the aircraft small they could have a larger number of them and could hit the enemy harder.

**Miss A. Kennedy** (*Companion*): It seemed to her that in order to have a feeling of security a lot of spare aircraft carriers were wanted because if one was sunk it might upset tactics in that area for a very long time. During the war when an aircraft carrier was sunk it fell on the general public as a great disaster because there was not another one to put in its place.

**Commander Torrens-Spence**: In his paper he had dealt with the vulnerability of aircraft carriers and the circumstances in which they had been lost during the war—not one by shore-based aircraft.

Admittedly, there were the ordinary risks of any ship being sunk by mine or submarine and, if there were no fighters, of being bombed. There was the difficulty of replacing carriers and in the last war that was particularly noticeable because they started without enough. They had surplus battleships and not enough carriers. If they had not enough carriers and could not replace casualties, then they could not prosecute the war, because he saw no way of covering shipping movements except by local fighter protection. In war it was necessary to provide for the replacement of all essential weapons or else suffer defeat. For them, the aircraft carrier was one of these weapons.

*A few stills taken from the films illustrating deck landings and take-offs from aircraft carriers, which were shown by Mr. W. G. A. Perring, F.R.Ae.S., Director of the Royal Aircraft Establishment, are given on the following pages.*

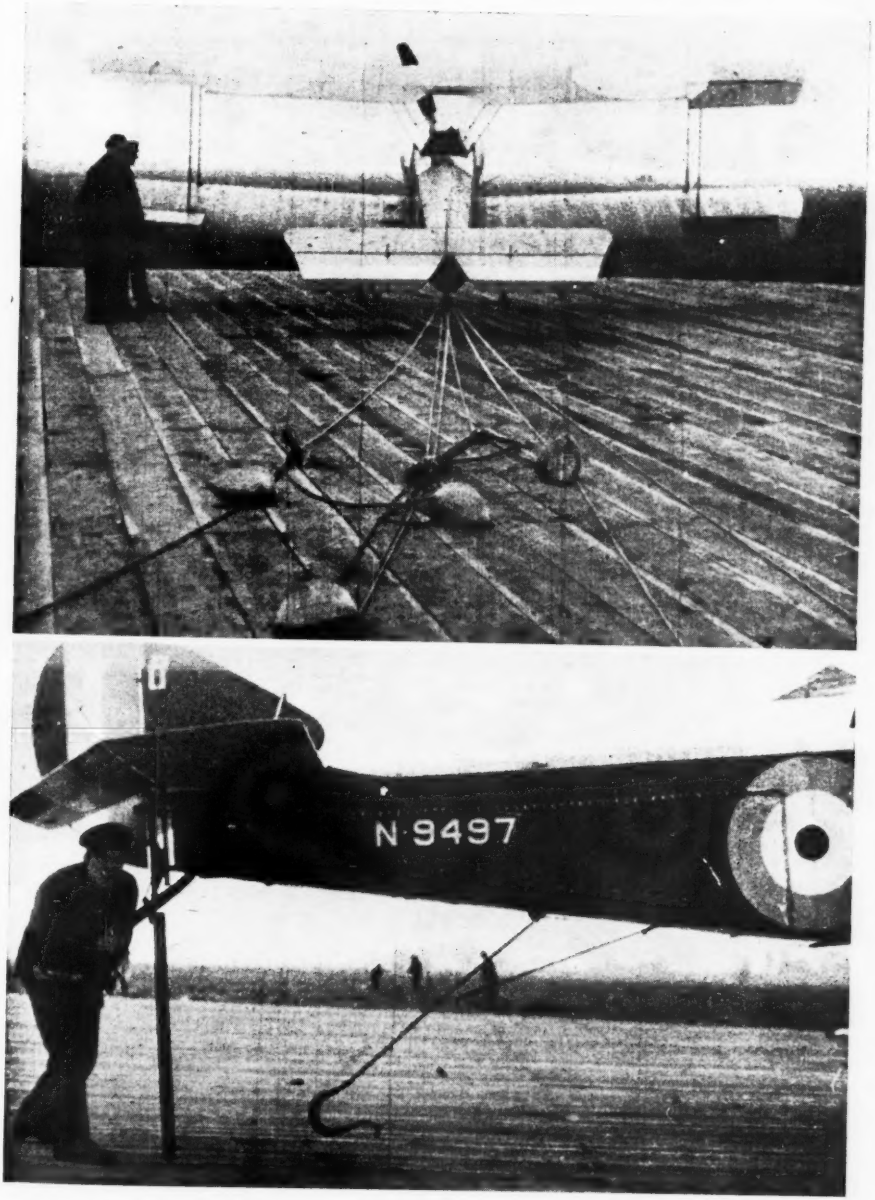


Fig. 1.
Arrester experiments with a Sopwith Pup at the Isle of Grain in 1923. Ropes weighted down by sandbags were picked up by an arrester hook fitted to the aircraft.

Fig. 2.

(Above): Tail-down launching of a Firebrand V from H.M.S. "Illustrious" in 1946.

(Below): (1) The tensioning and holding back arrangements for tail-down launching. (2) A close-up of the forward bridle.

Fig. 3.

(Reading from the top down): (1) The catapult trolley fitted to H.M.S. "Pegasus" in 1936 for launching Hawker Ospreys. (2) A Grumman Wildcat being launched from H.M.S. "Implacable" in 1944 by the tail-down method with a single hook. (3) A four-point launching trolley with the legs collapsed. (4) A Hurricane ready to be catapulted from a rocket-propelled "P" catapult which was fitted to merchant ships to enable aircraft to be catapulted for convoy protection duties. The trolley was driven forward by 14 three-inch cordite rockets and provided a launching speed of 60 knots.

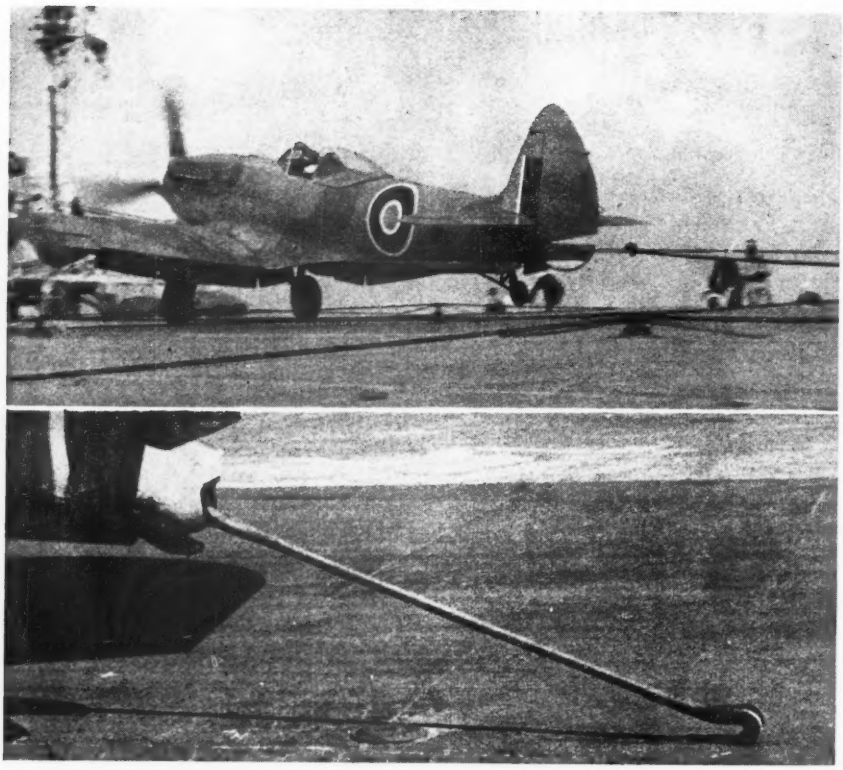

Fig. 4.
A Seafire XVII fitted with a sting-type hook to reduce pitching motion, landing on H.M.S "Triumph" in 1946. (Below): A close-up of the sting-type hook.

Fig. 5.
Rocket-assisted take-off of a Fulmar from H.M.S. " Biter " in 1942. Three-inch cordite rockets were used but were replaced later by five-inch rockets of a flashless type. The rocket cases were jettisoned after take-off.

## DISCUSSION

**Mr. E. Norman Wilson**: When the Vampire took off was it in any way loaded, for the take-off seemed to be very short indeed, particularly for a jet aircraft?

**Lieut. Commander Brown**: The Vampire was flown off at 8,200 lb.

**Mr. Perring**: The Hornet was also lightly loaded, and was flown off at about 15,000 lb.

**A/Cmdr. Vernon Brown,** C.B., O.B.E., M.A. (Ministry of Civil Aviation, *Fellow*): The very early trials in the *Furious* were half deck landings and there was a crash screen of ropes which hung down from an erection near the funnel in the centre of the ship.

He regretted that Mr. Perring was not able to show photographs of the old H.M.S. *Slinger* which was doing catapult trials about 1916 or 1917. He wondered if anyone knew that experiments were made in a ship of flying-on to a wire which was hung outboard and stretched between two posts or booms? In the early days landings on it were made by Gerrard in a Pup. On the wire was a loop and on the top of the Pup was a hook, and they just flew under and aimed at the loop on the wire!

**Mr. Perring:** The experiments he had shown were at the Isle of Grain. The arrester gear comprised a rope held back by sandbags.

**Mr. A. G. Elliott** (*Fellow*): What motive power had been used at take-off in those experiments? It appeared to him that cordite could be a convenient source of motive power for that purpose. It had been used in the Services for starting internal combustion engines and it had been developed quite successfully for starting turbines.

**Mr. Farren**: Many forms of motive power had been used at one time or another for the take-off. He could not say exactly what was used in the particular experiments shown. At Farnborough they had a cordite-operated catapult and had also used the energy stored in a flywheel.

The Germans had used what was virtually a steam generator in their hydrogen peroxide system for the V.1. This had one great advantage in that, by the use of a free piston which was discarded, the additional inertia was very low.

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## Evening Session—In the Chair: Dr. H. Roxbee Cox, F.R.Ae.S.

## FINAL DISCUSSION AND SUMMING-UP

**Mr. A. N. Clifton** (*Fellow*): A question which seemed to have run through most of the day's talks was, how could they give the Navy the best possible aeroplanes? As Mr. Farren had pointed out, there were certain handicaps and difficulties which were in the way of the aeroplane designer who tried to supply the best possible article.

It seemed to be taken for granted that the range required for Naval aircraft was greater than the range for a land-based aircraft. He could not quite see why that should be so because as a Naval aircraft operated from what was, in effect, a moving aerodrome it should be able to move nearer to the object it was attacking than the land-based machine and the range requirement should be less.

He agreed with Admiral Slattery that there was virtue in smallness and they all liked to try and keep their aeroplanes as small and compact as they could. Unfortunately, the weight of armament which aeroplanes were required to carry seemed to be increasing greatly and it was impossible to avoid aeroplanes also increasing in weight and size.

It would help if larger limits were placed upon the dimensions to which the aeroplane designer had to work. One thing which imposed restrictions was the size of the lift. He appreciated that there was a limit to the size of the hole they could make in the deck

of an aircraft carrier, nevertheless they were accustomed to make large holes in the decks of flying-boats and aeroplanes and the limit seemed to be the whole width of the aeroplane. Why could not the lift size of the carrier be increased?

Why were carriers made largely of steel? There was armour plating, but he believed he was right in saying that in some respects light alloy had proved to be as efficient as steel for this. There might be a possibility of considerable weight reduction in the carrier if greater use could be made of light alloy. Presumably they could then have larger carriers of the same displacement which could handle larger aeroplanes.

The need for high lift devices was imposed by the approach speed limitation. In the absence of such a limitation shore-based aircraft could avoid some of the devices and could be smaller in dimensions. With increased approach speeds Naval aeroplanes also would be smaller and less elaborate and would meet more easily the long periods without maintenance which Admiral Slattery wanted.

There appeared to be two limitations in connection with the development of arrested landing. One, connected with the mechanics of arrester landing gear; they hoped that some improvement in the direction of higher speed would prove possible as far as that was concerned. The other was that which might be imposed by the inability of the pilot to fly the aeroplane on to the deck at higher speeds. It seemed to him that not much was known about that subject. One fact which had some bearing on it was that almost any Tom, Dick or Harry, driving his motor car along the road, seemed to be able to miss another motor car coming in the opposite direction at a relative speed of a hundred miles an hour, without difficulty. This rather tended to show that if they had good control a speed of a hundred miles an hour relatively did not cause any difficulty in judgment. Some investigation of that subject might be done by means of a device similar to the Link Trainer in which the pilot's reactions were ascertained with a view to establishing the limit in approach speed imposed by the human factor.

**Mr. J. L. Bartlett** (Naval Construction Department, Admiralty): They wanted to be quite clear on the question of the limitations imposed by the carrier. Prior to 1940 they worked to a limited size on aircraft of 40 ft. long, 18 ft. folded width, 13 ft. 6 in. high and 11,000 lb., eventually going up to 15,000 lb. and they actually built ships to take aircraft of those dimensions. The lifts in the *Illustrious* class were only 22 ft. wide and they could not take up much more than 18 ft. It was because the limitation of size was cramping the design of aircraft that they had that meeting to which Sir Charles Lillicrap had referred.

The whole object of the meeting was to see to what extent the aircraft designers wanted the dimensions relaxed. They relaxed everything, including the length, span and height, folded width and take-off conditions, with the result that they would now be prepared to put into any new carrier an aircraft lift 44 ft. wide and 54 ft. long. He did not think there was anything in the carriers now building that would limit the aircraft.

There were reasons that were hinted at in the morning session as to why, although they could take aircraft of 25 ft. folded width, only a folded width that would assist stowage, from the point of view of the number that could be stowed on an aircraft carrier, was used. It was infinitely better to carry 60 really good machines than 100 poorer ones. But they had not reached the limit of the carrier.

They could not, and he did not think they ought to, give particulars of the latest types of arrester gear that were being developed. But if it was a case of 100 miles an hour landing speed and they allowed 20 or 30 knots for safety, there would be no difficulty if they liked to make it 120. He would not

like to say that they had reached the limit as regards arresting gear, but if they put in gear to the limit he doubted if the pilot would be able to use it.

**Mr. J. Smith,** C.B.E. (Vickers-Armstrongs (Supermarine) Ltd., *Fellow*): Two important factors would govern future development. First, more attention would have to be paid to devices for producing more lift from a wing and in this respect it must be borne in mind that fundamental changes in the shape of the aircraft were rapidly being incorporated. Swept-back wings now appeared to be essential and he was doubtful if the work necessary to develop high lift devices would be completed in time to have useful applications. The design of aircraft carriers was another important point and a useful exchange of information had taken place at that meeting at the Admiralty four years ago. Several concessions improving the efficiency of the aircraft had been given then and, in his view, the matter should be pursued. Periodical meetings between aircraft and carrier designers would result in mutual benefit. Designing Naval aircraft with folded wings (necessitated by carrier design) resulted in increased weight and, if this could be avoided, the Navy would get better aeroplanes.

The present methods of deck landing were out-dated and becoming dangerous and some new device was essential. If a modern fighter was designed without the chassis, a saving in weight of approximately 1,000 lb. was obtained, with a resulting gain in speed of the order of 13 per cent. A further point on deck landing was that on jet aircraft, the best position for the pilot was in the nose of the aircraft. In his view this necessitated a complete review of the crash barrier provisions in the near future. Was anything being done in this connection?

**Mr. J. E. Serby** (D.M.A.R.D., Ministry of Supply, *Fellow*): He hoped that Admiral Slattery's suggestion to go for a fundamentally good aeroplane and not bother too much about making sure from the start that it could finally carry all the operational equipment anyone might want, would bear fruit in the right quarter.

The meeting between aircraft designers and the Admiralty four years ago had been a real landmark in the development of Naval aircraft. The concessions obtained then in regard to dimensions and so on had been so valuable that he felt a further meeting would prove equally valuable. He hoped it would be forthcoming.

He had been a little disappointed not to hear more mention of the profound effects on Naval aircraft which the advent of the jet engine had had. Perhaps it was not fully realised by everyone that in dispensing with the propeller and using a plain jet engine—and that was the type the higher performance aircraft would use—they had changed the control characteristics both for landing-on and taking-off, considerably.

In the past a pilot flying an aeroplane with a propeller in front had been relying to a large extent on the effects of the slipstream which the propeller gave over the tail and over the wings in increasing lift and the ability to boost the lift by increasing the power in the engine and to do the reverse of that when he wanted it by cutting the engine, all of which was of great advantage in landing. They had lost many of those advantages now and interesting work was in progress trying to find out the best technique for landing jet-propelled aeroplanes.

Further advances in landing the aeroplane on the carrier were needed. It was obvious that landing was far more difficult than taking off, which had now become almost fully automatic. In landing, far more was left to the pilot but the landing operation should be made automatic. This stage might be a long way off, but again, work was in hand on the automatic or blind landing of aircraft. This was highly desirable since it would eliminate the risks and dangers of what was certainly the most crucial stage of carrier flying.

**Mr. H. Sammons** (D. Napier & Son, Ltd.): He had been somewhat surprised that none of the speakers had made any request for a reduction in fuel consumption of the gas turbine in order to obtain the desired increase in the range of the aircraft. He would confine his remarks to the case of the small high-speed aircraft only.

As an engine builder he felt that the aircraft designer had a right to expect power plants of very much increased thermal efficiency. It was possible to do this and he thought they had put up long enough with consumptions round about the pound of fuel per pound of thrust. They must have engines with consumptions at least 30 per cent. less. Reductions in consumptions were possible in two ways—either with heat exchangers and the like, or by raising the pressure ratio. The latter was by far the better because it would mean smaller engines and it was their job in future developments to aim at a power plant giving these figures.

Whether for Naval aircraft or otherwise, an engine with a high thermal efficiency and a small frontal area must help towards reducing the drag of the aircraft. It was possible that the gas turbine, either as a jet, or with a propeller, could reduce that very much. He felt certain that in the case of the jet it was possible to quadruple the power per unit of frontal area of the engine, as compared with the engines in operation on jet aircraft to-day.

They had a reputation abroad for designing and producing gas turbines for aircraft in short spaces of time. The Vice-President of a big American aircraft factory had asked him recently how they designed and developed gas turbines in nine months. He had replied that he did not know. But the American said that was the story they had in America.

That sort of propaganda did tremendous harm.

The engine that he envisaged, which would increase the thermal efficiency to the figure given, would require three to four years to design and develop and it would be a good performance if done in that time. He begged all aircraft designers to forget that only a short period of time was necessary to design and develop a highly efficient gas turbine power unit.

He agreed with Admiral Slattery's demand that maintenance should not be made easy, but should be abolished, and they would do their best, so far as the engine side was concerned, to make that possible; but he would suggest that the Services themselves could benefit in that direction by collaborating with the manufacturer and also the aircraft designer. He was a firm believer in the inspection in the Service being reduced to the minimum. That was necessary because, fundamentally, every time they inspected a part that was satisfactory—*i.e.* when such inspection involved taking down and reassembly of parts—when it was put back again it was often not in as good a condition as before.

Their experience was that the number of troubles they got on test on reassembly after inspection was just as great as the mistakes that were made on the first assembly. They should aim at giving the Services means of making the essential inspections without taking the engine or the aircraft adrift. He knew it was perfection, but it should be their aim. This called for close collaboration between the Industry and the user.

**Rear Admiral (E) C. P. Berthon** (A.M.R. Department, Admiralty): There must be more active development in the maintenance and repair aspects of design. Recent experience might be misleading because they were maintaining aircraft which were largely built under the stress of war conditions. But, if recent experience was any criterion the maintainer and repairer was going to have a difficult time and his burden should be eased by increased attention to his problems.

Points which required attention appeared to be:

First: A greater knowledge of the Service life of the various components leading to a knowledge of the periods at which it was really necessary to inspect, or replace.

Second: Better arrangements for making the necessary inspections. At present a great deal of work was being done which in itself led to wear and tear.

Third: Interchangeability of components should be closely watched to provide the certainty that repair by replacement could be practised in the field and in the factory.

Fourth: The repair of the components should be more easily achieved or alternatively, these should be built to have a definite life and then be discarded.

American practice tended more to the latter conception.

The realisation of these objectives needed a greater allocation of man-power to the drawing offices and to research into performance under Service conditions; this was the type of man-power which was now difficult to provide, but every effort should be made to provide it if British aircraft were to hold their own.

Neglect of these points inevitably meant that man-power in the servicing organisation was being used uneconomically. Unnecessary work on aircraft in the Service due to matters which might have been better arranged in the initial stages, was surely unprofitable.

**Captain Pearson** (U.S. Navy): In the early part of the war the Americans had fighters that were not folded. It was found that 35 per cent. more aircraft could be stowed by folding the wings. It was estimated that 5 per cent. was lost in rate of climb and a half of one per cent. at top speed because of folding the wings. The pilots said they would prefer the non-folding wing. For all circumstances where there was a definite limitation of carrier space, dictated in their case, even then the aeroplane would be better with the wing folded. There was no question as to the policy which dictated the folding wing, rather it prescribed the requirements. Although the pilots preferred the non-folding wings, the limitation on the number of carriers and the great demand for even greater numbers of fighters to protect the fleet, dictated a policy of folding all carrier fighter wings.

**A Speaker**: In the film the main undercarriage of the Mosquito appeared to be particularly well behaved on deck landings. He believed he was right in saying that the undercarriage relied on a shock absorber. As the undercarriage was such an important feature of Naval aircraft would some one comment on the relative performance of an undercarriage with rubber in compression and other types based on oil in compression?

**Captain C. C. Hughes Hallett**: He supported Captain Pearson's views because he thought that the over-riding factor was how many aircraft could be got into the ship. The unfortunate user or operator ought to be brought in also for the discussion between aircraft designers and the Director of Naval Construction, because he was the person who had to work the gear.

It had been clearly brought out that the arrester gear must accept higher rates of entry and he thought it was indicated that there was no insuperable difficulty in doing that. But, the designers of the aircraft and the ship, respectively, having agreed, it was probably the unfortunate users who had to suffer because they got a longer pull-out or there was less room on the deck. With the arrester wires the pull-out dictated the case if the forward arrester wires ensured that the aircraft having picked up the wire, went into the barrier as well. He emphasised the need for the three parties to consider design and not merely for it to be considered by designers alone.

The question had been asked as to why the Navy was asking for long range, which appeared to be unnecessary. What they really wanted was not range but endurance in time. If they had short endurance aircraft they

were continually turning the carrier force into the wind in order to land-on. They might possibly take-off out of wind, but they could not land-on out of wind and it might become completely impossible to operate the force for the necessary time into wind unless they had a long endurance aircraft. Constantly turning into wind made an absolutely insuperable problem in some cases.

He had had the impression from many speakers that it was now the normal practice for take-offs to be assisted. While he could accept that it was a requirement of the future and was probably wise, at the moment this was not the case. The real percentage of assisted take-offs was about four per cent. of all take-offs and it was not practical to meet the operational requirements with the gear and aircraft supplied and go much higher than that because of the difficulties. Admittedly there were in use fewer types of aircraft which could not do assisted take-offs; but, the fact remained that the modern carrier now operating did not really have a high percentage of assisted take-offs.

**Lieut.-Commander E. M. Brown** (Royal Aircraft Establishment): He was an adherent of the tricycle undercarriage, but experience had shown him its shortcomings. The Americans had been conducting deck landing experiments with the Lockheed Shooting Star but the success of the experiments was doubtful because severe bouncing was experienced during the dummy deck landings on the aerodrome.

He had made deck landings with the Airacobra and the Vampire. Lately he had been conducting experiments deliberately trying to bounce some of the tricycles and the results were startling. The Meteor, which had long been looked upon as a non-bouncer, he had managed to bounce up to twelve feet and the Vampire he could guarantee to bounce any time. The technique for getting those bounces might be a little unorthodox, but there were many pilots who would be quite likely to do, unintentionally, what he did.

Designers might look upon the tricycle as an easy means to the safe arrival of the aircraft on deck, but with the ordinary undercarriage they had to adopt the long stroke oleo to lower the rebound ratio. He thought that introduction was also necessary to the tricycle undercarriage. In fact, he had flown a long-stroke tricycle undercarriage fitted to an Albemarle—24 inches of stroke—and that, it was impossible to bounce. He had dived it into the aerodrome almost up to the maximum diving speed of the aircraft and he had not yet succeeded in leaving the ground at all. He suggested that if that introduction was made, success was assured. In any case, he regarded undercarriages as obsolete because he regarded them as redundant. If their weight was saved it could be put into something more valuable, extra fuel, or more ammunition.

**Captain C. W. Jones** (*Assoc. Fellow*): Commander Torrens-Spence had referred to his difficulties in the Middle East in getting a sufficient number of fighters on board the carriers. About that time large numbers of Fulmars had been received in the Middle East which were to be reinforcements. The Fulmar had a large centre section and they were sent by sea in cruciform cases. Those cases were such that they could not be off-loaded in Alexandria because they could not get them off the docks, because of their width compared with the streets. They had to be off-loaded in the Canal Zone but there was no crane there to lift them!

He believed there was not a Naval port in which more modern fighters could be landed and got out of the docks at the moment in the whole country, for the same reason. Aircraft had to be embarked—that was, embarked when they were static and not when they were flying—so it should be kept well in mind that when they were sent boxed as reinforcements, there must be a limit on the designed sizes.

He thought it true that none of the engines used in Naval Aircraft to-day reached the

specified time they were supposed to, before they required a major overhaul. The average time was about 30 per cent. of the time they were supposed to last before they were due to be inspected. When aircraft were used operationally, it was also true that few of them ever reached the stage of a major inspection. At least, that was his experience.

**Commander E. G. Savage**: As a simple user of aircraft he thought they should not lose sight of the fact that the whole object was to destroy the enemy.

Admiral Slattery had asked for a good aeroplane on which to hang weapons. He was fully in agreement, but in war it was not possible to know in the very early stages of design, or even after the aircraft was produced, what weapon was likely to be required in the near future. Weapon design changed quickly, sometimes on account of tactical changes or because new and better weapons were invented. If they were to have a good aeroplane they must have a good and efficient organisation to put the weapons on the aircraft quickly when they required them.

In the Pacific their air strikes would have been far more efficient if their fighters had been capable of carrying rockets. The British Pacific fleet was a big organisation and took many thousands of men to keep it running. It existed for one purpose only—to put aircraft over the Japanese Islands. Anything which would double the effectiveness of those aircraft on arrival would be of great importance in the naval economy of the future.

**Dr. H. Roxbee Cox**: It seemed from Mr. Bartlett's remarks that with a lift size of 55 ft. by 44 ft. there was a good chance of using Naval aircraft which did not fold, leaving the problem one of stowage—one which apparently would well repay some careful reconsideration.

It was interesting to hear from Mr. Serby that the flying technique of deck landing with jet-propelled aeroplanes was in course of study. Was the device of the thrust-spoiler regarded as useful for that particular purpose? Those who were concerned with jet propulsion motors were well aware that those engines did not accelerate or decelerate as quickly as they would like. Consequently, the device of the thrust-spoiler was produced so that an aircraft could come in at full throttle with the thrust spoiled. Then, if there was a baulked landing, increased thrust could be obtained quickly by unspoiling the thrust. It seemed that some such device would have great value in deck landing.

He thought Mr. Sammon would agree that it was not always the engine of lowest fuel consumption which was the engine for the job; in many cases the controlling factor was the weight of the engine plus the weight of the fuel for the job that had to be done. Sometimes it must work out that it was better to have a light engine with a relatively heavy fuel consumption, than a heavier engine with a lower fuel consumption.

He had great sympathy with Mr. Sammon's viewpoint on the time of development of turbine engines but, in point of fact, the story of ultra-rapid development was caused by the rapid construction of the first prototype. There was no doubt that some extraordinary times had been achieved between putting pencil to paper and the first running of the first prototype. It was after that, that development began and that might be a long business. It was the remarkable performances which their designers had put up in reaching the first run that had given rise to the idea that the whole development of the gas turbine engine could be done in phenomenally short periods.

**MR. PERRING**: He thought the general conclusion of the meeting favoured concentrating attention first and foremost on the design of the best aircraft—a view he strongly supported.

He had been particularly interested to hear from Mr. Bartlett of the possibility of further

improving arrester gear apparatus. He was sure the figures which he had mentioned during the discussion would stimulate designers and that designers would soon take advantage of any possibility of employing higher landing speed.

They were experimenting at Farnborough with a drag flap fitted to a jet aircraft to get better landing characteristics. In addition to providing increased drag, there was a marked change of trim; consequently it was proposed to couple the drag flap with an elevator trimmer since it was especially important to avoid a change of trim during the critical

He fully supported the view expressed period of landing.
about the need for crash-barrier work. The new aircraft raised a number of important crash-barrier problems. Tricycle undercarriage aircraft and jet aircraft, for example, could not be handled by existing forms of barrier.

He was glad to hear Lt.-Cmdr. Brown's whole-hearted support of the idea of getting rid of the undercarriage altogether.

**Dr. Roxbee Cox**: He was interested to hear that Mr. Perring believed that a thrust spoiler had advantages over a drag flap. With the latter, the braking effect got less as the speed went down, whereas the thrust spoiler provided an almost constant effective braking force.

**COMMANDER TORRENS-SPENCE**: He could not argue strongly with Lt.-Cmdr. Brown on undercarriages because he had done little flying for the past two years. But he rather thought Lt.-Cmdr. Brown agreed that the tricycle was a better proposition from the pilot's point of view. On the whole, although it had been denied that it was impossible to make a tricycle bounce, he had never seen one do so and would like to hear more about those actual experiments where tricycles were being bounced. A tricycle would bounce if landed fast with the nose down, in the same way that an ordinary aeroplane with its undercarriage in front of the C.G., would bounce.

He thought they should go carefully in the matter of increasing folded width. The ship constructors were trying to give them as many cubic feet of space as they could in the ship and the aeroplane constructors were trying to give them as many efficient military aeroplanes as they could stow into that space. If they altered the folding arrangements so that the aircraft took up ten per cent. more space, those aeroplanes would then be ten per cent. less use because there would have to be that proportion fewer in the ship. A slight loss of rate of climb was well worth having if it enabled a significantly greater number of aeroplanes to be carried and operated. It was no good having enormous lifts to take aircraft of such a size that you could only put about ten of them in the hangars. What was wanted was lots of aeroplanes in the ship and on the deck, and under those conditions, only a small lift was needed.

He knew something about reversible pitch airscrews and it would seem to be absolute murder to reverse the pitch before touching the deck. Once you had hit the deck in a carrier the arrester wire would stop the aircraft much more efficiently. If the pitch were reversed after catching a wire they would get no effect and if they attempted to reverse before they had caught the wire they would be likely to crash into the round down.

There was much to be said in favour of jets for shipboard use, but the principal snag was endurance. With a jet aeroplane you could get higher performance from the same size aircraft, which was the first thing wanted in a ship-based aircraft. There were other obvious advantages such as safer fuel and no need for warming up the engines; ranging up aircraft for warming up before flight was a time-wasting nuisance. Reduced maintenance was an important advantage because of the saving in living accommodation and stowage for suppplies for maintenance

ratings, this being a much more critical consideration than it was ashore.

**MR. BODDINGTON**: The difficulties he had stated with regard to arresting were difficulties and not limitations, yet. He was as optimistic as Mr. Bartlett in getting to higher entry speeds, but wished to emphasise that such speeds would only be attained by a more fundamental approach to the design and a fuller understanding of all the factors which contributed to the retardation. Gears for 75 knots were under test, but something of the order of 100 knots might be needed in the near future. This was entry speed and not the approach speed.

Full account was being taken of the work done on barrier cables and their experimental technique was based on this work. The arrester gear did, however, embody fundamental differences in that the wire was stretched across the deck with a comparatively short span and had to pass through about 20 pulleys on its way to the gear under deck. At present they had not established to their satisfaction a mathematical link between the two stages referred to by Dr. Roxbee Cox. The first stage was becoming more important, but could not be separated from the second stage, certainly in present designs.

The physiological problems referred to by Mr. Bartlett were real ones but it was considered that they were not yet near the physical limit. The rate of application of acceleration was extremely important, but this limiting rate fell well outside reasonable practice. Experiments were being made to study these effects under catapulting and arresting conditions. Higher accelerations might produce temporary black-out or distorted vision caused by the flattening of the eye ball, but he considered that if the aircraft was catapulted at a high take-off speed well above its $V_s$, these would be of minor importance. He had take-off speeds of $1.3V_s$ in mind.

In arresting, the problems were generally covered by the crash conditions—25g was catered for. Safety barriers at present gave something of the order of 6 to 10g, which was again well within the general crash conditions under which a movement of the head and stretch of the neck had been measured up to 16 inches. The time of application was important and it was probable that the correct parameter was the product of acceleration and time.

It was appreciated that the present barrier arrangements were not satisfactory for future aircraft, particularly the soft-nosed jet aircraft with the pilot well placed for view, but not so happily placed for a barrier engagement. A guard to prevent the barrier rope entering the cockpit was not a satisfactory solution. New means must therefore be discovered. As the arrester gear was first an emergency gear—any pilot in those early days who picked up a wire had to stand a round of drinks in the ward room afterwards—so he believed that the barrier, now an emergency gear, might possibly become the means of arresting the aircraft of the future if it could be done without damage to the airframe. The problems were numerous and both they and the Americans were actively engaged on research for solutions to these problems.

He did not know what the limitation in flying speed would be—whether it would be a failure on the pilot's part to fly the aircraft on to the deck, or an increase in the accident rate. Mr. Clifton's analogy to the two cars passing on the road was not complete without comparing views and control. If the pilot had perfect view with the basic landing instruments placed so that he had not to remove his attention from the deck during the approach, and the aircraft was under full control, then higher speeds were certain.

For the deck landing trials of the Mosquito, the undercarriage was oleo-pneumatic.

**MR. FARREN**: There were five divisions into which the discussion fell. First, the problem, mainly a technical one, of landing.

They had all agreed that landing on carriers required further research and development. New methods were necessary if they were to succeed in making the jet aircraft do what it was, in principle, capable of doing. They had reached conditions which were approaching the limit of human skill and endurance and they would have to consider whether it was practical or politic to ask any more of the human element.

Mr. Perring had supported him in his emphasis on the need for a really good view for the pilot. Captain Fancourt had made several interesting points on the same subject. They might not know that Captain Fancourt was the hero of the first landing of the Fairey IIIF in the *Vanguard*.

An important point was that some of the most successful Naval aircraft were really adaptations of R.A.F. aircraft—and, excellent as they were in many respects, they were not designed for deck landing.

Second, there was the question of duration or range. He had been careful to emphasise in his paper that duration of flight, and not merely distance covered, was important. He felt that the Navy's requirements for duration and range were virtually unlimited. He could recommend a very interesting recent book by Sir William James to anyone who wished to get a clear idea of the way in which these requirements were implicit in Naval strategy and tactics. Naval aircraft needed more economical power plants, judged on the basis of the total weight of the whole design. The limit to the internal tankage was simply the capacity of the aircraft—and external tanks would be added as circumstances required.

Third, there was the carrier. Those who spoke on behalf of the carrier had been very handsome. He thought they had spoken from their hearts and he hoped the outcome of the discussion would be a better understanding all round.

He was particularly glad to note the general favourable response to the proposal for eliminating the undercarriage from Naval aircraft and making the necessary changes in the carrier. He wished to disclaim any credit for having originated this idea, but he was a strong advocate of its advantages and a believer in its practicability.

Fourth, there was the question of flexibility or versatility in Naval aircraft. He saw no reason why a versatile aircraft, with a flexible layout, should not be a good aircraft. He agreed entirely with Admiral Slattery that the first requirement was to secure a good aircraft, but there were many examples to support the contention that a good aircraft could always be put to a variety of uses, which was what the Navy needed.

He had no doubt—and he was glad that the Fifth Sea Lord was present at this discussion—that the mass of detailed requirements, both in function and equipment, which the Naval staff had in the past forced on Naval aircraft, had been particularly burdensome when associated with the special requirements of carrier operation. This had probably been done with a complete conviction that it was necessary, but he felt that the whole of their experience had proved that it was not the right way to produce good aircraft and that some way of doing better must be found. This was an expression of a resolution and not a criticism.

Associated with this point was that of designing Naval aircraft so that they could, at the right time, carry the right weapons. While it was no doubt impossible to lay down a general rule, he still felt that, in practice, the weapons would change more rapidly and more frequently than the aircraft and that the aircraft must be so designed as to be capable of accommodating weapons which were not foreseen at the time of its design. To say that this was impossible was not in accordance with experience. Clearly there were exceptions, which must be met by exceptional methods. But he saw no reason to believe that the experience of the past was not a fair guide to a great deal of the future. He recognised the wisdom of Mr. Scott Hall's

view that the right thing to do was to try to collect all the best ideas about aircraft and weapons and to make that the starting point of any design. But he believed that it was essential to keep the aircraft, as a weapon carrier, flexible in layout.

Finally, there was the old problem of balancing all these considerations and making the right compromise; size and weight of aircraft, problems of handling and of stowage, the engineering and operational economics. The meeting mentioned by Sir Charles Lillicrap was one place at which these matters could be discussed as a whole. The problem was not entirely technical. The question how many aircraft of one sort would be as good as, or better than, so many aircraft of another, could not be settled only by engineers. But the engineer should be admitted to the councils in which those discussions took place and the final decisions were made. Most people concerned with the design of aircraft were happy to work to specifications provided that they were satisfied with the fundamental basis of those specifications.

This was a problem which he felt had been tackled successfully during the war. They had found a way of bringing together the engineer, the scientist and the user and letting them work out in free discussion a conclusion in which all had reasonable confidence. No one class could or should claim the right to make the final decision, since none bore the ultimate responsibility. But each had a vital contribution to make and none should be excluded. From his experience, their methods in this matter were different from those of their late enemies and he believed that this was one of the reasons why the Germans had failed and they had succeeded. He felt that this was a lesson which should never be forgotten, and that the planning of the design of future Naval aircraft should be made in the light of that lesson.

**R. C. Abel** (*Assoc. Fellow*), *contributed*: Mr. Farren assumed that preparedness for war involved ship-based aircraft, but this was only true if very long-range shore-based aircraft were not equally efficient. That was to say, the characteristic advantage of ship-based aircraft was the operation from multiple mobile bases, of *short*-range aircraft which would be, for that very reason, superior to long-range aircraft of comparable types. Therefore Mr. Farren's assumption that long range was a first requirement for ship-based aircraft was somewhat bewildering.

A brief and convincing synthesis of this situation could be made, assuming three main categories of aircraft: —

(1) First-class fighters operating from decks fitted with all aids to take-off and landing.

(2) Guided missiles of about 700 miles range operated from ships.

(3) Civil flying-boats operating from natural and artificial inland waters.

The last-named could find numerous natural bases all over the Empire and were readily convertible to wartime transport and patrolling duties, but not to bombing. Shore-based guided missiles would need a range of many thousands of miles, from which bombers would have also to return. Ship-launched missiles need only cross somewhat more than half the width of any land area containing the target, anywhere in the world. Moreover, shore bases would draw the full weight of enemy attack on to their territory, even though, under atomic threat, all manufacture should have been done in peace-time.

Finally, ship-based fighters could meet enemy shore-based fighters on their mobile "home ground," anywhere they chose to intercept. Therefore the specification for ship-based aircraft should demand the very highest performance, relying on every possible advantage of launching, landing and closeness that only the ship could provide.

**MR. FARREN** (*contributed*, in further reply to the discussion).

**Sir Charles Lillicrap**: The chief "potentiality" of the aircraft carrier which he felt had

not been fully realised was, as remarked later by Mr. Perring, the use of power and mechanical advantages of all kinds, which could be provided in a ship relatively easily. The aircraft carrier, unlike a land airfield, must have available large sources of energy within it. For the take-off of the aircraft from the carrier energy was required in a form which up to the present could not be easily or economically derived from the carrier's own source of energy. Efficient catapults therefore required some additional source (*e.g.* cordite) but he was not convinced that by further review of the whole situation the two requirements could not be met by one source. Regarding the aircraft carrier and its aircraft as one weapon, development must go along this line if the highest results were to be achieved.

**Mr. Hollis Williams**: He had no recipe for designing for flexibility. Perhaps the best way of looking at the matter was to consider the opposite and its consequences. Precise compliance with every detail of a complicated specification designed to achieve a comparatively limited objective did not seem to produce good aircraft.

**Mr. Davenport**: He hoped he had not suggested that wing folding could be achieved for no penalty in weight. He could give Mr. Davenport particulars of a modern Naval aircraft with power folding with a structure weight percentage below 30. The final answer must be made in relation to such considerations as were brought forward later in the discussion by Captain Pearson, U.S.N.—30 per cent. more aircraft in a given carrier, 5 per cent. loss in rate of climb, ½ per cent. loss in speed.

**Captain Luby**: He recognised the efforts that had been made to provide the Navy with piston engines which it needed. He was now concerned that equally strenuous efforts should be made to provide it with the turbines it would need. His main point was that in these, fuel economy must rank high as a criterion. He was glad to note that Captain Luby put economy near the top of his list.

**Mr. Perring**: It was cheering to know that Mr. Perring was optimistic about the practicability of landing aircraft without undercarriages ashore. He himself had never doubted that this could be done under certain limited conditions. His earlier answer to Sir Philip Vian related entirely to operational conditions and, at the moment, he had insufficient knowledge to go further than in the answer he had given. But all past experience suggested that ingenuity and experience would continually reduce the restrictions in such a development. His main doubt at the moment was whether the arrester gear, as at present conceived, could cope with the high speeds of entry which would be involved. The obvious answer was that the arrester gear would have to undergo a radical change to meet this.

**Mr. Mitchell and Commander Beard:** He hoped that his answer to Sir Charles Lillicrap would explain more clearly what he had meant by his remarks about the development of catapulting and the application of the potential power of the carrier.

**Mr. Clifton and Mr. Abel**: It seemed to him that the essential reasons why most, if not all, Naval aircraft must have provision for long range were: (a) most Naval warfare involved large distances, and (b) aircraft carriers were fairly vulnerable. This did not rule out short-range operations (and for these the aircraft could profit in an obvious way) nor did it imply that shore-based aircraft did not require long range. He believed that in future practically *all* aircraft would require a much longer range than was useful at the beginning of the last war. In fact, experience by the end of the war proved this. Captain Hughes-Hallett had made a further point, which he had done his best to emphasise in his paper, that Naval aircraft required a large endurance. On both accounts the development of more economical aircraft was essential. He wished to emphasise once

again that a high-drag aircraft was basically wasteful.

**Mr. Bartlett**: It was encouraging to know that the Directorate of Naval Construction was so confident about the development of arrester gears for 100 to 120 knots entry speed. The experimental equipment now available at Farnborough should be invaluable to them in exploring a field about which at present too little was known.

**Mr. J. Smith:** He was glad that Mr. Smith agreed that the main problem of Naval aircraft now was to improve aerodynamic characteristics in landing. The barrier certainly needed thinking out again, but from what he had seen in the way of experimental work, he felt confident that this was not an insuperable problem so far as any probable ship-borne aircraft was concerned.

**Mr. Serby**: As the accredited agent of the Naval staff, in securing complete compliance with the almost overwhelming detail of their specifications, it would seem that Mr. Serby's head and hand had often to do what his heart did not believe in. It seemed to him that it was up to the aircraft designer to do more thinking for himself.

In regard to the influence of jet propulsion on carrier aircraft, and particularly the disappearance of the propeller slipstream as an aid to control, he was not convinced that an appreciable effect could not be obtained by the use of suction. If this were "fed" directly from the engine, then presumably its effect would rise and fall with the opening and closing of the throttle. The difficulty might be that there was too much lag, but experiment was necessary before an answer could be given.

A fully "automatic" landing was an ultimate development, particularly in relation to night operations. He felt that the first thing to do was to drive right away from the present "staggering in" method of landing which was far too much of a skilled gymnastic operation to be tolerated indefinitely.

**Mr. Sammons**: He was encouraged by his confidence in the ability of engine makers to produce a better thermal efficiency and at the same time a greater increase in power per square foot of cross-sectional area of the power unit.

**Lieut.-Commander Brown**: He had a profound respect for Lt.-Cmdr. Brown's experience and skill as a pilot and was quite sure that if an undercarriage could be made to bounce, Lt.-Cmdr. Brown would find a way to do it. But he felt there was some possible misconception. Surely it was not the arrangement of the wheels, but the energy absorbing characteristics of an undercarriage, which determined its ability to bounce. This was exemplified by the "long travel" undercarriage which Lt.-Cmdr. Brown mentioned. The potential advantage of a *nose-wheel* undercarriage was that immediately after touch-down the nose of the aircraft *could* be allowed (or possibly forced) to fall, thus killing the lift of the wings and preventing what was generally described as "ballooning off." Of course, if the speed were too high and the nose were raised, the aircraft could be flown off again. Possibly this was how Lt.-Cmdr. Brown had achieved his "bounces." No one with any experience of tricycle undercarriages believed that they were fool-proof, but it did seem that they held great promise of doing something to render Naval aircraft safer and more effective than the tail-wheel undercarriage and for that reason he believed that they would be widely adapted.

# CORRESPONDENCE

*2nd September*, 1947.

## War Aircraft Museum

I noted with interest in a current issue of a well-known American aircraft publication that the American Air Force authorities have just had a grant of 50,000 dollars to initiate and set up a permanent wartime museum of aircraft, engines and propellers for instructional and educational purposes.

As Chairman of the Royal Aeronautical Society's Special Advisory Committee to the Minister of Aircraft Production, I feel I must write and put on record that the members of this Committee put forward a similar plan in May 1945 to the then Minister of Aircraft Production and the C.R.D.

Sir Stafford Cripps reviewed this matter sympathetically and asked for certain memoranda on the subject.

Two members of the committee, Mr. Sidney Camm and the late Mr. Roy Chadwick, took considerable interest in the matter and we had a good scheme prepared, employing one of the wartime aerodromes, which I believe would have been of immense value to the coming generation of the Aircraft Industry and the R.A.F., and by correct planning and organisation could have been made mainly self-supporting.

Unfortunately at the conclusion of hostilities, with the change of personnel and the absorption of the M.A.P. into the M.O.S. this proposal has been lost sight of, together with many others.

As our Advisory Committee has now disbanded I am writing to suggest that this would be a matter in which the Society could well take an interest.

**Sir Roy Fedden,** M.B.E., D.Sc., M.I.Mech.E., M.I.A.E., M.S.A.E., F.R.Ae.S.

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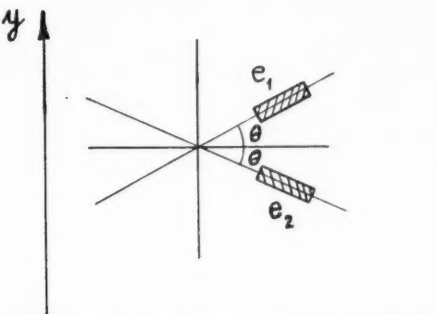
## On Dr. Redshaw's paper "The electrical measurement of strain."

*23rd May*, 1947.

With reference to Dr. Redshaw's lecture on "The electrical measurement of strain" published in the August 1946 Journal, and to Mr. J. K. Redman's letter on the same subject in the December 1946 Journal, the following may be of interest to those who are not already aware of it:—



Referring to the diagram, if $e_1$ and $e_2$ are the strains in the directions $\pm\theta$ to the $x$-axis,

$$e_1 = e_{xx}\cos^2\theta + e_{yy}\sin^2\theta + e_{xy}\sin\theta\cos\theta, \text{ and}$$
$$e_2 = e_{xx}\cos^2\theta + e_{yy}\sin^2\theta - e_{xy}\sin\theta\cos\theta.$$
$$\therefore \quad \tfrac{1}{2}(e_1+e_2) = \cos^2\theta\,(e_{xx}+e_{yy}\tan^2\theta) \text{ and}$$
$$\tfrac{1}{2}(e_1-e_2) = e_{xy}\sin\theta\cos\theta.$$

If it is required to measure the shear strain $e_{xy}$, it is usual to make $\theta = 45°$, in which case $(e_1 - e_2) = e_{xy}$ and $(e_1 + e_2) = (e_{xx} + e_{yy})$. The latter equation gives us a comparatively useless piece of information, since we cannot calculate the stresses $\sigma_{xx}$ or $\sigma_{yy}$ from it, although their sum $(\sigma_{xx} + \sigma_{yy})$ is equal to $\dfrac{E(e_{xx}+e_{yy})}{(1+\nu)}$

If, however, we take $\theta = \tan^{-1}\sqrt{\nu}$, then

$$\tfrac{1}{2}(e_1+e_2) = \frac{(e_{xx}+\nu e_{yy})}{(1+\nu)}$$

and hence

$$\sigma_{xx} = \left\{\frac{E}{(1-\nu^2)}\right\}(e_{xx}+\nu e_{yy}) = \frac{E(e_1+e_2)}{2(1-\nu)} \quad . \quad . \quad . \quad . \quad . \quad (1)$$

while $\tfrac{1}{2}(e_1 - e_2) = \nu^{\frac{1}{2}} e_{xy}/(1+\nu)$, which gives

$$\sigma_{xy} = \left\{\frac{E}{2(1+\nu)}\right\} e_{xy} = E(e_1 - e_2)/\nu^{\frac{1}{2}} \quad . \quad . \quad . \quad . \quad . \quad (2)$$

Equations (1) and (2) show that by a suitable arrangement of strain gauges, it is possible to measure a shear stress and one direct stress, using only two gauges. If Poisson's ratio is taken as 1/4, $\theta = 26.6°$, while if $\nu = 1/3$, $\theta = 30°$. Since there appears to be some doubt regarding the value of $\nu$, a mean value for $\theta$ of about 28° is therefore suggested, corresponding to $\nu = .28$.

This method of using strain gauges should be useful in, for example, stress diffusion work, where a knowledge of the shear stress, and the direct stress in the direction of the applied load, will usually be sufficient.

**W. J. Goodey,** Technical Department, Gloster Aircraft Co. Ltd.

# REVIEWS

**The Elements of Aircraft Propeller Design.** F. T. Meacock, A.F.R.Ae.S. E. & F. N. Spon Ltd., 1947. 12s. 6d. net.

There are designers and salesmen in the aircraft industry, particularly on the engine side of the industry, who believe the aircraft propeller to be, if not actually dead, at any rate *in extremis*. But the death rattle, if one could trust the story told to Mr. Midshipman Easy, can last a remarkably long time. These very designers and salesmen who were so sure, a bare twelve months ago, that the end really was in sight, are now beginning to feel that the patient is tougher than most aircraft patients.

Mr. Meacock need not be afraid his book will not sell because its subject is obsolete or even obsolescent. It will not only sell because its subject is one so vital to aircraft performance, but also because Mr. Meacock's own performance in writing the book is first-rate.

This book is intended to give a general survey of propeller design. The first section explains the basic principles of propeller aerodynamics; the second developments in propeller aerodynamic design; and the third section, developments in the mechanical design of propellers.

These sections clearly explain the basic aerodynamic and mechanical principles of aeroplane propellers. In fact, the explanation is so clear and simple that those who are new to the subject may be tempted to think that there is nothing in propeller design. For many years propeller design was wrapped in mystery and most aircraft designers and pilots have accepted the propeller as part of the mechanism designed by the experts.

It is an essential part and will be for most aeroplanes for many years to come. This book can be thoroughly recommended and the publishers are to be congratulated that, in the difficult conditions at present prevailing, they have put up such an excellent printing performance. The cover design is one which many other publishers might emulate for simplicity and effect.

**Gliding and Power Flying.** "String-bag." Oxford University Press. 1947. 6/- net.

For those who are about to fly, for those who are thinking of the not too-distant day when they will at least learn to glide, and for those who want to know what may be involved if they wish to join a flying club, this book will prove extremely useful. It is written by one who has flown high-powered fighting aircraft and who knows all the art and technique of gliding. It has the advantage over so many books on gliding and power flying that it is written in the free and easy and joyous style of one who clearly not only enjoys every minute he spends in the air, but has enjoyed, in this book, telling his friends, known and unknown, something about that joy and how it may be attained.

"Gliding and Power Flying" contains some of the clearest and simplest explanations the reviewer has yet met on soaring flight, of learning to fly a powered craft, and what is meant by "airmanship."

**The Escalator Method in Engineering Vibration Problems.** Joseph Morris. Chapman and Hall Ltd. 1947. 21/- net.

Captain J. Morris had a long struggle for recognition, but now that that recognition has come it is being given to him in well-deserved and full measure.

The years between the two world wars have seen signficant advances in methods of investigation into the strength of aeronautical structures, advances which have proved necessary through the increasing sizes and speeds of aircraft. Of these new methods the "escalator method," first put forward by Morris and Head in 1942, has proved of particular value in the solution of vibration problems. These problems are of great and increasing perplexity and their solutions by earlier methods, although theoretically possible, were so laborious as to make them practically impossible. Some idea of the wide scope of Morris and Head's method may be gathered from a few of the chapter headings: coupled engine torsional and propeller flexural vibrations; aircraft wing vibration; axial or longitudinal vibration of an aircraft; the pitching and yawing flexural vibrations of an aircraft; and periodicity of forced vibrations due to propeller blades passing "aerodynamic obstacles."

This is not a text book on the escalator method, but an account of that method, and a first-class account at that.

It is noted by the author that although he has been graciously granted permission by the Ministry of Supply to publish this book, the author alone is responsible for the statements made and the opinions expressed therein.

Any Ministry should have been proud to be responsible for such a book, but modern Ministries appear to have little or no pride in accomplishment.

**Aircraft Engines.** A. W. Judge. Vol. 2, 2nd Edition. Chapman and Hall, 1947. 36/- net.

The first edition of "Aircraft Engines" was published in 1941 and reprinted the following year. The present edition has been revised and enlarged so as to contain the latest available information about the high output class of reciprocating engine and gas turbine. The whole of the new matter has been included in a special chapter of some 65 pages. If certain gas turbines and jet propulsion enthusiasts are to be believed, the proportions in the next edition of "Aircraft Engines" will be reversed, so that this will be 428 pages on gas turbines and jets and 65 pages on the history of reciprocating engines.

The author has done an excellent job of work and this is a book which all those interested in aircraft power plants should have on their shelves. As with all their publications Chapman and Hall have done their share of the work superlatively well.

**International Air Transport.** Todd Reference Books Ltd. London and New York, 1947. 25/- net.

It is a brave man who edits any reference book on air transport in this Year of Peace, 1947, and an optimistic publisher who produces such a book. One can only assume the editor and publisher are trying to do good turns for one another, but the reviewer is not at all sure either have done a good turn to the buyer of "International Air Transport."

This book is full of pronouncements, portents and piffle, of much that should have been left out, and of little which should be left in. Aviation personnel these days move with jet-like jerks from one firm to another or one Ministry to another and no publication which moves as slowly as a paper-controller may direct, stands a chance of being correct when it comes under review. It is difficult to see a space for this on our reference shelves.

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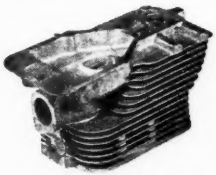

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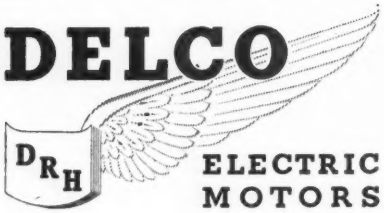


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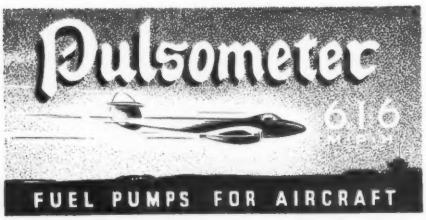


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